The University of Chicago

ESPANOLA DISTRICT, ONTARIO

A DISSERTATION

SUBMITTED TO THE FACULTY
OF THE OGDEN GRADUATE SCHOOL OF SCIENCE
IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

BY

TERENCE THOMAS QUIRKE

Private Edition, Distributed By
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CONTENTS.

CHAPTER I.

	Page
Introduction	1
General statement and acknowledgments	1
Location and area	1
Transportation and communication	1
Previous work	3
Agriculture and lumbering	3
Topography	4

CHAPTER II.

Summary	5
Table of formations	6

CHAPTER III.

Physiography	9
Origin of cliffs and canyons	12

CHAPTER IV.

Stratigraphy	19
Pre-Huronian	19
Sediments	19
Distribution	19
Stratigraphic relations	19
Character	19
Micaceous slate or phyllite	20
Micaceous schist or greywacke schist	20
Staurolite schist	20
Quartzitic schist	21
Basic intrusions	21
Granite	22
Age and relations	23
Huronian	24
Bruce series	25
Mississagi quartzite	25
Distribution	25
Character	25
Thickness	28
Origin	28
Bruce conglomerate	28
Stratigraphic relations	28
Distribution	29
Character	30
Origin	32
Espanola group	33
Bruce limestone	34
Stratigraphic relations	34
Distribution	34

PAGE

Character and thickness 35
Origin 35
Espanola greywacke 35
Stratigraphic relations and distribution 35
Character 35
Thickness and origin 36
Espanola limestone 36
Stratigraphic relations and distribution 36
Character 36
Thickness and origin 38
Serpent quartzite 38
Greywacke member 38
Stratigraphic relations and distribution 38
Character 38
Thickness and origin 39
Quartzite member 40
Stratigraphic relations and distribution 40
Character 40
Thickness and origin 42
Cobalt series 42
Gowganda formation 43
Stratigraphic relations and distribution 43
Character 43
Slate member 47
Conglomerate dykes 47
Microscopic determinations 47
Thickness and origin 47
Keweenawan diabase 49
Distribution 49
Character 49
Microscopic determinations 50
Quartz diabase 50
Diabase 51
Olivine diabase 51
Gabbro porphyrite 51
Contact metamorphism 51
Absorption 51
Microscopic determinations 52
Quaternary 55
Glacial 55
Post-Glacial 55
Lake sands 55
Stratified clays 56
Marlekor or imatra stones 56

CHAPTER V.

Structure 59
General structural conditions 59
Summary of events 59
Field data 61
Overthrust faults 61

PAGE
Minor faults 62
Thrust faults 62
Mechanics of the postulated movements 64
Character of the stresses 64
Physical nature of the members involved 64
Shape of the members 65
Applications to the Espanola structure 67
Assumptions 74
Facts in conclusion 75

Index 89

Illustrations.

Map 180 A. No. 1624. Espanola area, Sudbury district, Ontario in pocket.
Plate I. A. Skyline from a hill near Webbwood looking north 77
B. Decadent cliff on the shore of Moon lake 77
II. A. Typical outcrop of Bruce limestone 79
B. Solution hemispheres in Espanola limestone 79
III. A. Ripple-marks and mud cracks in Serpent quartzite 81
B. Pebbly, quartzitic dykes cutting Espanola greywacke 81
IV. A. Serpent quartzite showing the lining due to feldspar and quartz laminations 83
B. Post-Glacial, interlaminated clay and sand deposits 83
V. Marlekor or imatra stones 85
VI. A wooden block compressed in a direction transverse to the grain 87
Figure 1. Location of Espanola area 2
2. Diagrammatic section of formations in Espanola area 8
3. Diagrammatic section of Gowganda formation of the Cobalt series, Foster township 46
4. Generalized cross section of Espanola area 60
5. Flexure of column:
(a) With fixed or square ends.
(b) With rounded end.
(c) With one fixed end and one rounded end 66
6. Idealized section of the deformed Huronian terrane 68
7. Supposed lens shape of Bruce and Cobalt deposits before deformation. 70
8. Hypothetical structure of Huronian formations at Espanola at the time of:
(a) First thrust fault.
(b) Second thrust fault.
(c) Third thrust fault.
(d) The overthrust fault 73

Espanola District, Ontario.

CHAPTER I.

INTRODUCTION.

GENERAL STATEMENT AND ACKNOWLEDGMENTS.

The following report is an account of the geology of a small area in the neighbourhood of Espanola, Ontario. The field work was commenced during the summer of 1914 by W. H. Collins of the Geological Survey of Canada, this area being one of a series of key areas which were to be studied with the object of correlating the geological succession at Sudbury with that of the classic "original Huronian" district near Sault Ste. Marie. A preliminary report on this larger problem has already been published.[1] After two weeks' work in Merritt township the geological investigation of the Espanola area was delegated to the present writer.

Valuable assistance was given by John R. Marshall and E. W. Todd, who mapped many of the lakes and roads of the area, and by the writer's fellow geological assistants, W. E. Cockfield, H. J. Heath, and Arthur Benoit. Grateful acknowledgments are due Professors R. D. Salisbury, A. J. Johannsen, and R. T. Chamberlin of the university of Chicago for many suggestions and criticisms.

LOCATION AND AREA.

The position of Espanola area is shown in Figure 1. The area mapped is 16 miles long from east to west, and $7\frac{1}{4}$ miles wide, having thus an area of 116 square miles. It includes all of the townships of Foster and Merritt, two-thirds of Hallam, and a strip $1\frac{1}{4}$ miles wide across the south side of Shakespeare, Baldwin, and Nairn townships.

TRANSPORTATION AND COMMUNICATION.

The area is readily accessible. Espanola station, on the Soo branch of the Canadian Pacific railway, is 43 miles west of Sudbury, and Webbwood is 5 miles farther west. The Algoma Eastern railway traverses Merritt township from north to south, the stations of Espanola Mills and Merritt being near the north and near the south end of the district respectively. There are several good highways in Hallam township, including the trunk road between Sault Ste. Marie and Sudbury, which

[1] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914.

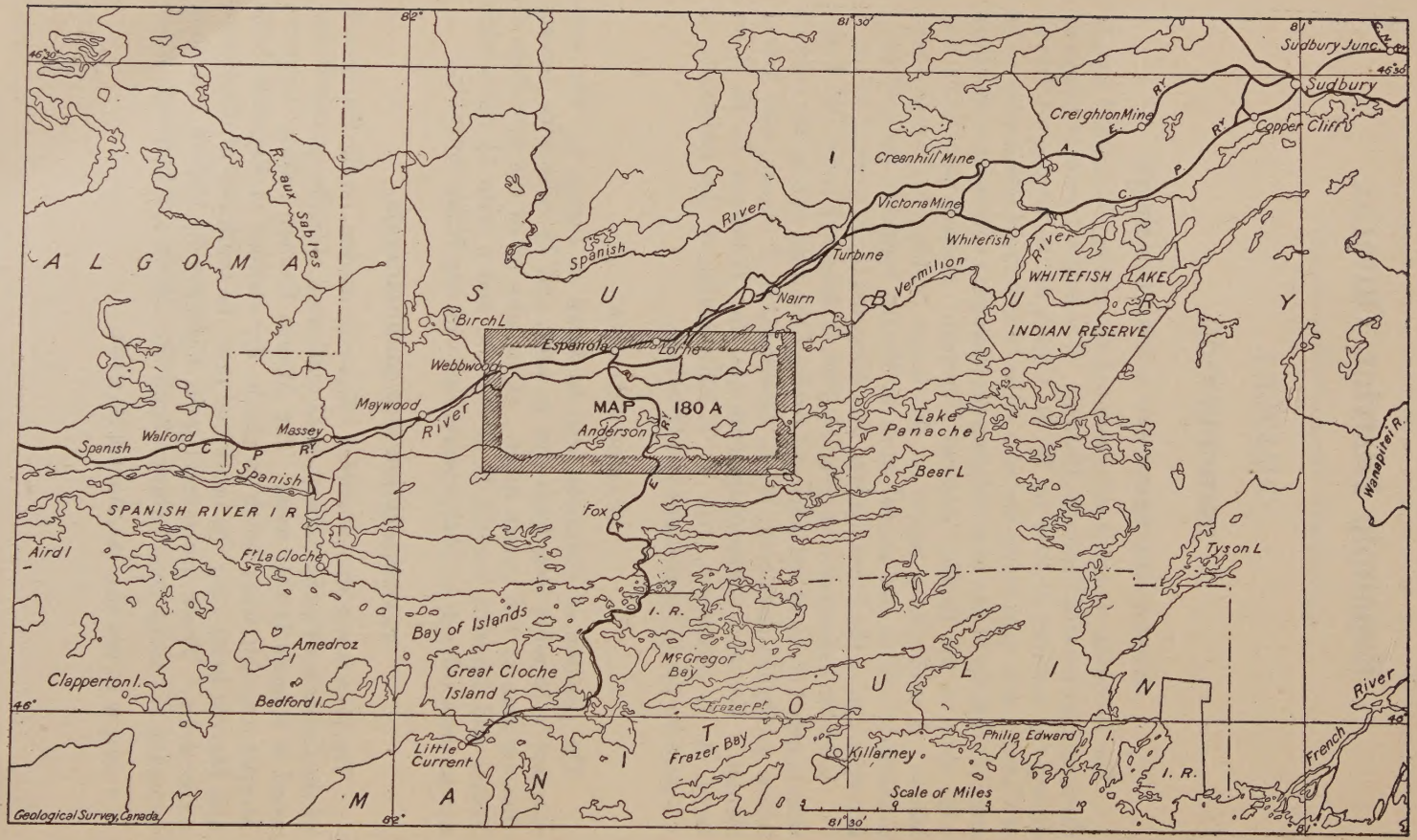

Figure 1. Location of Espanola area.

runs through the northern part of Hallam and Merritt townships. Foster township and the southeastern part of Merritt township are without any roads except a few "tote" roads which have not been in use for many years. Vermilion river crosses the northeastern part of the area to join Spanish river on the boundary between Foster and Merritt townships. From that point Spanish river continues in a westerly direction across the northern part of the district. There is also a good canoe route from the mouth of Vermilion river, through Brazil, Elizabeth, and Augusta lakes into lake Panache.

PREVIOUS WORK.

The townships of Merritt and Foster are in Sudbury mining district, and were mapped in the southwest corner of the Sudbury sheet;[1] in his report on that district R. Bell[2] made no mention of the Huronian rocks near Espanola. For the Ontario Bureau of Mines, Dr. A. P. Coleman[3] made a reconnaissance trip, apparently chiefly along the railway, during the summer of 1913. The southeastward continuation of the formations found at Espanola north of La Cloche mountains, has been reported upon by Bell in the French River report.[4] In his report on the Sudbury mining district, Bell has also described the outcrops around and south of lake Panache.[5] The rocks south and southeast of Espanola have been described again by Coleman.[6] In his preliminary report, Collins[7] has stated for the first time the succession and correlation of the Espanola formations.

AGRICULTURE AND LUMBERING.

There are a few small farms in the less rocky parts of Merritt, Baldwin, Hallam, and Shakespeare townships, but, since they are nearly all on a sand-plain they are not very productive. The towns of Webbwood and Espanola Mills have populations of a few hundred people apiece. At Espanola all the people derive their living from the Spanish River Pulp and Paper Mills. This company has a head of water of 62 feet at its dam, although the natural fall was less than 20 feet. The waterfall was formed by the Spanish river cutting through lake deposits down to a diabase dyke. The mills enable the local settlers to dispose of their timber profitably. In earlier days the whole sand-plain was covered with spruce; of that forest only stumps remain. The pulp mills at Espanola

[1] Geol. Surv., Can., geological map of Subdury mining district, Sheet No. 130.
[2] Bell, R., Geol. Surv., Can., Ann. Rept., vol. V, 1889-90, pt. F.
[3] Coleman, A. P., Ont. Bureau of Mines, 23d Ann. Rept., 1914, pp. 221-222.
[4] Bell, R., Geol. Surv., Can., Ann. Rept., vol. LX, pt. I, p. 19.
[5] Bell, R., Geol. Surv., Can., Ann. Rept., vol. V, 1889-90, pt. F.
[6] Coleman, A. P., Ont. Bureau of Mines, 23d Ann. Rept., 1914, pp. 219-221.
[7] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, pp. 13-14.

take all the spruce which is brought in from the surrounding country. All the pine was cut long ago. Oak is not very common and brings the settlers a good price. There is a mill at Merritt which dresses considerable maple and cedar.

TOPOGRAPHY.

The topography formerly mature is now in the rejuvenated stage. As a result of Pleistocene glaciations the country now abounds in cliffs, lakes, marshes, waterfalls, and old lake flats formed in the post-Glacial stages of lake Huron. There are many lakes in the district. If a line were drawn from the northeast corner to the southwest corner of the area, nearly all the lakes would lie on the south side of the line. North of such a line there is a sand-plain broken by irregularly distributed hills. The hills rise from flat surfaces of sand-filled valleys. The basal slopes plainly are buried far above the curves normal at valley bottoms. Most of the greater elevations are diabase masses, which form many bold and striking hills, but in general, the relief is less than 300 feet, and the drainage is very youthful. The hills rise to an evident accordance of summit levels, and many of them are flat topped.

CHAPTER II.

SUMMARY.

This district is part of the eastward continuation of the "Original Huronian area," and, for the most part, its rock formations belong to the Huronian system. There are also older basement rocks consisting of much metamorphosed sedimentary schists and slates, and intrusive greenstones and granite, collectively referred to hereafter as pre-Huronian. In most areas where it is known, the pre-Huronian series of sediments is cut in many places by acid intrusions, but, in this particular area, granite is found only in the northwest corner at a distance from these sediments. The sediments are said to be traceable here and there into the typical pre-Huronian formations of Sudbury district. They are thought, therefore, to be equivalent in age to the Sudburian series of Coleman[1] and possibly to the Temiskamian of Miller and Knight.[2]

Overlying these ancient and greatly metamorphosed schists and greenstones, and in faulted contact with them, are two series of steeply tilted, and in many places faulted, Huronian sediments. These are part of sediments on the north shore of lake Huron which have been described most recently and differentiated by Collins.[3]

Following the nomenclature proposed by Collins, the writer will refer to the lower of the two associated series as the Bruce, and to the upper as the Cobalt series. In the Espanola area, the Bruce series is represented by the Mississagi arkose and basal conglomerate, the Bruce conglomerate, the Espanola group (which includes the Bruce limestone, the Espanola greywacke, and the Espanola limestone), and the Serpent quartzite. In the Cobalt series, there are slate conglomerate, beach-like conglomerate, and well-bedded, clean slates, which are classified collectively as the Gowganda formation. The Cobalt series is unconformable upon the Bruce series.

The Huronian rocks are cut by a series of diabase dykes and sills which characterizes the whole region. Fortunately these injections do not occur so abundantly that they prevent a determination of the sedimentary succession. They seem to have come later than the faulting near lake Tulloch, in the Espanola area, but in other parts of the Timiskaming region—specifically, near Algoma station—it is evident that some of the faults cut some of the diabase injections. It is likely that the

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[1] Coleman, A. P., "The nickel industry," Mines Branch, No. 170, Ottawa, 1913.
[2] Miller and Knight, Ont. Bureau of Mines, vol. XXII, pt. II, 1914, p. 127.
[3] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, p. 26.

diabase injections and the faulting were more or less contemporaneous and that they are kindred products of the same parent cause.

The faulting, for the most part, is parallel to the general strike of the rocks, which is from north 40 degrees east, in the southeast part of the area, to nearly true east in the south-central part. The dips of fault planes are not known, but they are supposed to have been southward at the time of rupture. These faults are reverse or thrust faults, they have stratigraphic throws up to several hundred feet, and their displacements are of unknown but much greater amounts. The northern outcrops of the Bruce series seem to be almost certainly overthrust upon the eroded surface of the pre-Huronian sediments. All the Huronian rocks have been much disturbed. In some places they are vertical; intense shear zones between the massive quartzite beds testify to the great amount of intra-formational movement which has taken place in addition to the great displacement of the thrust faults. Throughout most of Timiskaming region, the Bruce and Cobalt series dip less than 30 degrees, but in the Espanola area the dips are nearly everywhere more than 30 degrees, and for the most part between 65 and 90 degrees. The dip is prevailingly southward. There are many indications that the thrust was not normal to the strike of the fault planes. The testimony of sheared conglomerate is particularly eloquent in proving that there was great lateral displacement, but no evidence was found which shows the extent of this movement. The rocks, by their metamorphism, show the effect of great thrust forces.

The Pleistocene formations which lie directly upon the Pre-Cambrian rocks, are represented by gravelly fluvioglacial deposits, bouldery till, and partly stratified clays, but chiefly by lake sands which form extensive flats. The stratified clays and sands are particularly extensive in the northern half of the area.

Table of Formations.

In the following table the formations are arranged in order of age, the youngest above.

Quaternary			
Post-Glacial	Lucustrine sands and clays, and cliff talus.		
Glacial	Gravel and boulder clay.		
	Great unconformity		
Huronian			
Keweenawan	Orogenic diastrophism, and diabase injections.		
	Igneous contact		
Cobalt series			
	Gowganda formation. Massive "Slate" conglomerate member		400 ft.
	Greywacke and slate		400
	Bedded conglomerate		650

	Unconformity	
Bruce series	Serpent quartzite	8,000?
	Espanola group	
	Espanola limestone	25
	Espanola greywacke	280
	Bruce limestone	150
	Bruce conglomerate	400
	Slight unconformity	
	Mississagi quartzite	4,000
	Great unconformity	
Pre-Huronian	Orogenic diastrophism and granite intrusions.	
	Igneous contact	
	Basic intrusions.	
	Igneous contact	
	Schistified sediments.	

The correlation of these formations, and their particular nomenclature are not discussed here; they are being treated in the work of larger scope by Collins. Any intention to correlate the rocks north of lake Huron with the well known formations south and west of lake Superior is disclaimed. The use of the name Huronian in this report should not be interpreted as equivalent in meaning to either upper, middle, or lower Huronian as used by geologists of the United States, nor is the term pre-Huronian intended to mean rocks older than all of the commonly called Huronian formations found south and west of lake Superior.

It may be well to emphasize the difference among the unconformities above noted. The unconformity which follows the Keweenawan and which preceded most of the Cambrian period is unquestionably of the "revolutionary" or era-ending type. It is found around the world, in almost all places in which both the Proterozoic and Cambrian formations occur; it is practically universal. The pre-Huronian-Bruce[1] unconformity is no less notable. It succeeds profuse vulcanism, and intense diastrophism, and it represents a long period of very advanced erosion. The unconformity between the Bruce and the Cobalt series is more of the character of a profound inter-periodic unconformity. The other unconformities mentioned are considered to be of the order of interformational breaks, and of slight significance.

[1] It is thought convenient to denote the unconformity following the pre-Huronian and underlying the Bruce series, as the pre-Huronian-Bruce unconformity. Similarly the peneplain which was developed after the Keweenawan injections, and which was older than the Cambrian formations, will be called the Keweenawan-Cambrian peneplain. This is an expansion of the German usage of coupling the names of glacial epochs in order to specify the interglacial epoch, such as the "Günz-Mindel-Interglacial-Zeit." Penck, A., and Brückner, E.: Die Alpen im Eiszeitalter. vol. I (1909), p. 111.

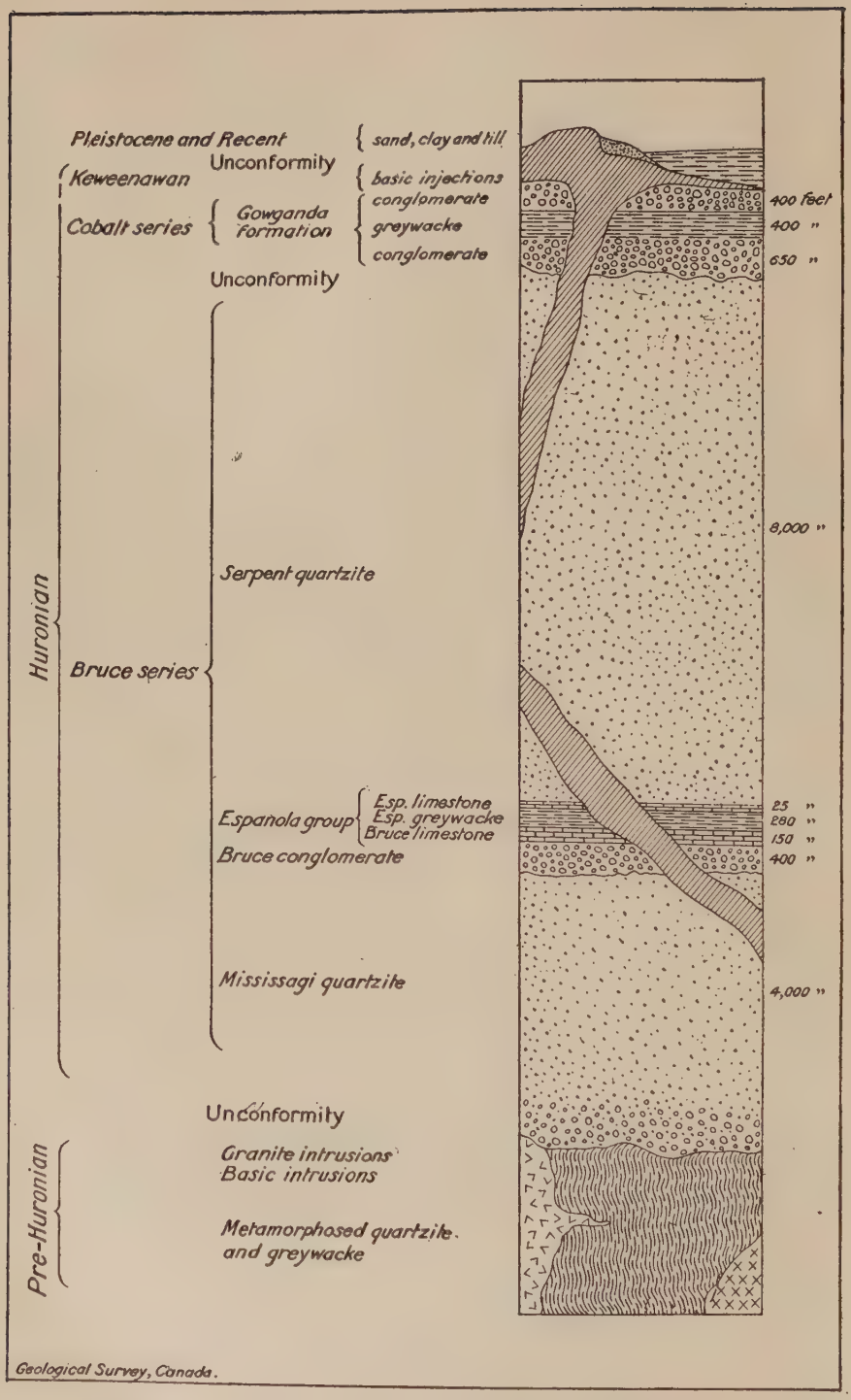

Figure 2. Diagrammatic sections of formations in Espanola area.

CHAPTER III.

PHYSIOGRAPHY.

The Espanola area shows a local phase of the physiography of northeastern Ontario. In considering the history of any area one must take into account the evidence provided by its environs, and for that reason much of the following discussion must relate to the larger physiographic unit of which the Espanola area is a small part.

Before the deposition of the Bruce series, it is certain that the underlying pre-Huronian slates, schists, and greenstones were intensely metamorphosed and very deeply eroded. The nature of the pre-Bruce surface cannot be determined in the Espanola area, but we know from the relations elsewhere in the country north of lake Huron that it was a well weathered land surface of low relief. Before the Bruce series was deposited, the pre-Huronian sedimentary series had been truncated and the land surface reduced to a peneplain.

Between the deposition of the Bruce and the Cobalt series, the area apparently was not subjected to so much erosion as during the pre-Huronian-Bruce peneplanation; erosion advanced enough, however, to remove the overlying formations in other localities down to the Bruce limestone.[1] The approximate equality of folding in these two Huronian series shows that the emergence of the lower, before the deposition of the upper, was of the non-orogenic type. Some time after the deposition of the Cobalt series, the sedimentary formations were intruded by diabase sills and dykes, probably of Keweenawan age. Before many of the intrusions, but after some of them, the district was greatly elevated by thrust faulting and folding.

Before Potsdam time this elevated surface seems to have been reduced to a peneplain. In northern Ontario this peneplain was the site of deposition during the Silurian period and probably also in the Onondagan epoch. Between the Onondagan epoch and the Pleistocene period the region was probably land, and during that interval the Palaeozoic sediments were removed. The physiographic history of that time, however, is largely a matter of conjecture based upon what is known of adjoining parts of the continent.

Almost every one who has written of Timiskaming region has described the peculiarly even skyline (Plate IA). No one has questioned its existence, but there has been little agreement as to the time of its origin. It seems certain that there was a period of early Palæozoic

[1] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, pp. 24-25.

deposition, which lasted into the Niagaran epoch of the Silurian period.[1] Therefore, it might appear that the peneplanation is post-Silurian. On the other hand, Weidman[2] reports that the clear-cut peneplain of the Pre-Cambrian region south of the Great Lakes is buried under the surrounding Potsdam sandstone. He suggests a former much wider distribution of the Potsdam than now exists, and a very wide pre-Potsdam peneplanation[3]. Martin concludes[4] that the trend of evidence suggests an early origin of the peneplain which is over the whole lake Superior region, perhaps late Proterozoic or early Cambrian. M. E. Wilson[5] believes that the surface of the Timiskaming region previous to Silurian deposition was probably of low relief, and that the present surface is an exhumed pre-Silurian land area; he continues that the evidence there does not show that the Kewagama region has ever been under the sea since the Palæozoic era, and that the youngest rocks present, except the Pleistocene, are the Silurian.[6] Schuchert[7] states that Onondagan corals spread into the Hudson Bay region as well as to the south; and in his map accompanying the article quoted he indicates a sea connexion between south Ontario and James bay during the Ithaca-Chemung epoch. He does not specify his basis for the latter extension. The Onondagan epoch seems to be the latest time at which the Timiskaming region was under the sea. Thus the region has been one of subærial status since as late as the Onondagan epoch.

The first cycle of erosion since then has been thought by some to have ended with the uplift of the so-called Cretaceous peneplain. M. E. Wilson[8] points out that we have no evidence that the Cretaceous peneplain ever extended over this area. Ten years before, A. W. G. Wilson[9] had said that in the extreme northwest of Canada the strata classed as Cretaceous are found resting on a peneplained surface, and that in New York, in Wisconsin, and in Michigan, there are remnants of a Cretaceous peneplain; furthermore, he stated that Devonian sandstones are found bordering the general region, which suggests that it was above sea-level and subject to erosion during at least part of the Devonian period. In regard to the peneplained surfaces in Wisconsin and Michigan, Wilson quoted the work of Van Hise, but Van Hise,[10] himself, says of the Wis-

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[1] Barlow A. E., Geol. Surv., Can., Ann. Rept., vol. X, pt. I, 1897, p. 27.

[2] Weidman, S., Jour. Geol., vol. XI, 1903, p. 309.

[3] Weidman, S., op. cit., p. 313.

[4] Martin, Lawrence, U. S. Geol. Surv., Mon. 52, 1911, p. 89.

[5] Wilson, M. E., Geol. Surv., Can., Mem. 39, 1913, p. 23.

[6] Op. cit., p. 33.

[7] Schuchert, Chas., Bull. Geol. Soc. Am., vol. XX, 1908, p. 540 and note No. 77.

See also Chamberlin and Salisbury, Geology, vol. II, p. 467 (1904); and Stuart Weller, Jour. of Geol., vol. X, p. 428 (1902).

[8] Wilson, M. E., Geol. Surv., Can., Mem. 39, 1913, p. 24.

[9] Wilson, Alfred W. G., Jour. Geol., vol. XI, 1903, p. 658.

[10] Van Hise, Chas., Science, New Ser., vol. IV (1896), p. 59.

consin and Michigan regions, that in calling the age of the Wisconsin peneplain Cretaceous, *it is no more than conjecture*; and writing of the Michigan plain, he says it is about 100 feet higher than the Wisconsin plain, about 150 miles away, and that they are both *probably* part of the same, much more extensive plain, and *probably* Cretaceous in age.[1] Several years later, R. D. Salisbury[2] added, "There is some reason for thinking that the important topographic features of the central Mississippi basin are chiefly of late Tertiary or post-Tertiary origin, developed from a late Tertiary peneplain now represented by the summits of the higher hills and uplands of the region. . . . It is true that these summits have sometimes been interpreted as remnants of a Cretaceous peneplain; but the conclusion is not firmly established, and the alternative suggestion is entitled to consideration."

There is no need of going further afield to show that the age of the supposed, very widespread peneplain is not determined. However, it seems safe to say that the Canadian shield had been reduced to very low relief before Silurian times, and that the Onondagan limestones as well as much of the Silurian sediments were deposited across the present divide between Hudson bay and the Great Lakes. The drainage, consequent to the uplift of this area of deposition, has removed entirely the Devonian limestones, and all except scattered patches of the Silurian deposits, and has modified but slightly the underlying crystalline rocks which were already of only low relief. Although the superposed drainage cut across hard and soft rocks without selection, and perhaps caused the topography of that time to be marked by cliffs, gorges, and rock bound canyons, and by a definite horizon to which the hills attained, yet, long periods of erosion must have removed such rugged features before Pleistocene times, and another origin is to be suggested for the relatively youthful system of drainage which was almost entirely disorganized by interglacial processes and by the glacial deposits. It is possible that the country was uplifted and eroded after Devonian submergence, reduced to the suggested base level by the beginning of Tertiary times, and uplifted again in a late Tertiary epoch. Subsequent to this uplift, erosion proceeded perhaps to early maturity before the Glacial period commenced. Thus the present major relief may have been made entirely since late Tertiary times.

Although means of dating the physiographic events in Timiskaming region between Pre-Cambrian and Pleistocene times are scanty, it seems certain that there must have been a period of base level in late Palæozoic times, so that it is likely that a topography in old age was rejuvenated by a Tertiary uplift, and that by Pleistocene times it had been changed to

[1] Op. cit., pp. 219-220. The italics are the author's.
[2] Salisbury, R. D. "Outlines of geologic history," Willis and Salisbury, 1910, p. 266.

one of early maturity. Maturity is suggested, for in Timiskaming region some divides are well marked and unbroken in places for miles. Old age is suggested for the topography at the time of the supposed Tertiary uplift, as the even crests of the quartzite ridges and the flat tops of the diabase masses testify to a former stage of far advanced erosion. However, it is not supposed that evidence for determining the ages at which these processes had become marked is to be found within the central land area; and least of all within the small area specifically considered in this report; but it is recognized that the physiographic history must be decided by the tracing of peneplains and other units of physiography into the formations of known age which border the province. Further, it is suggested that all land surfaces in the Timiskaming region since the Keweenawan-Cambrian peneplain[1] have had an accordance of summit levels by "inheritance."[2] The present accordance of summit levels may be the direct descendant of the great Pre-Cambrian peneplain which unquestionably characterized the present land area.

ORIGIN OF CLIFFS AND CANYONS.

The quartzite and the diabase hills are decidedly steep sided and many of them have high cliffs, although they have been subjected to much glaciation. Many of the hills have quartzite lower slopes with a diabase ridge or backbone; the quartzite has been sheltered on the lower flanks of the hills by the more resistant diabase. A striking example of this phenomenon is found in the northeastern part of Espanola area in Merritt township, lots 1 and 2, concession VI. Diabase is more resistant to the forces of erosion which have been at work in that region than the quartzite, in spite of the fact that it weathers now more rapidly than the much less soluble quartzite. At first thought, it may seem unreasonable to admit that the diabase cliffs rise above the quartzite by reason of the toughness of diabase in resisting glacial abrasion, whereas quartzite is fractured readily, and is carried away by plucking and other ice action. Such, indeed, are the properties of the rocks; but, in some places, the space between the top of the diabase and the top of the quartzite, which represents the amount of differential erosion, measures scores of feet and this seems a large amount to attribute to selective abrasion. Furthermore, many things point to a small amount of glacial cutting generally, although grooving, roches moutonnées, and other relatively minor traces of glaciation, are abundant, and some of the cliffs were approximately in their present stage of development before the end of the Wisconsin glaciation, for there is little talus at the base of many of them. Nevertheless, if the origin of every cliff was due to

[1] See footnote No. 1, p. 7.

[2] Daly, R. A., Jour. Geol., vol. XIII, 1905, p. 108.

selective processes during glacial and interglacial epochs, and the writer is of opinion that most of the cliffs of this region were so developed, then, in order to make so much difference between the amount of quartzite and the amount of diabase that was removed by cliff action and abrasion, there is required a great total of erosion. Cliff recession requires enormous transportation service to maintain its continuation, and the Pleistocene ice-sheets are thought to have supplied that transportation.

Many cliff faces are the loci of contact metamorphism. In many places, where contact between diabase and quartzite is close to a steep slope, the shattered quartzite has broken away and fallen from the face of the diabase mass, thereby forming a pile of quartzite block talus at the foot of a diabase cliff. Examples of the influence of the contact zones upon the topography are not uncommon. North of Thessalon, especially in Rose and Bridgland townships, the diabase cliffs are prominent. South of the lake in section 28, Rose township, there is a high hill due to the protrusion of a diabase dyke, as a core, through the quartzite formation. Between the diabase and the quartzite there is a gap 2 to 3 inches wide. The quartzite is very much fractured near the plane of contact, and the diabase rises with cliffs above the quartzite, forming the ridge of the hill. Also in section 19, Rose township, there is a prominent hill of the same character, in which the diabase core rises 20 to 30 feet high above the top of the quartzite, as a long, narrow, even crested ridge. In Espanola area there are similar hills, some of which are indicated on the diagrammatic cross-section on the accompanying geological map. In lot 10, concession IV, Merritt township, the diabase and quartzite hill which rises from the sand-plain has developed a cliff on the south side, evidently by the falling away of the quartzite from the diabase contact. These examples prove that, under conditions which have affected this region, diabase is a more resistant rock than quartzite, and that cliffs tend to form at the shattered contact of quartzite and diabase.

This process does not explain all the cliffs, nor does it explain the canyons in the massive diabase. Furthermore, there are some cliffs of quartzite, although they are not so common as the diabase cliffs. On the border land between Rose and Bridgland townships, and particularly near the corner of these two townships and Haughton and Galbraith, there are many diabase intrusions, which typically are bounded by cliffs. In lot 12, concession VI, Bridgland township, a deep canyon runs east and west through one of these diabase masses. The south rim of the canyon seems to have been rounded by ice scour, and the north side is extremely precipitous. One-fourth mile northeast of this canyon, the diabase mass faces east over a widespreading swamp land in a precipice as high as 300 feet. This cliff is broken by a hanging valley

which discharges at a height of 150 feet above the level of the marsh. Its debouchure is marked by a great alluvial cone made up of diabase blocks of all sizes up to 10 feet in diameter, but the stream which runs through the valley is very small, much too small to have carried the huge blocks which are part of the alluvial cone. In many cases the larger diabase masses are bordered by cliffs, and at its contact with greywacke the diabase rises high above the more readily eroded sedimentary rock. Steep-sided, V-shaped valleys and cliffs characterize the diabase of the region.

Usually it has been assumed that the cliffs and canyons are all of pre-Glacial origin, but perhaps they are merely pre-Wisconsin in age, and largely of interglacial development. When it is remembered that there were four epochs of glaciation, the higher degree to which quartzite has been eroded as compared with diabase seems less remarkable; especially is this so because of the manner in which glaciers pluck off and carry away accumulated debris, and so clear the way for weathering processes, particularly in the case of rocks already fractured by contact metamorphism. Contact shattering and glacial transportation greatly increase the scope and effectiveness of weathering. Epochs of interglacial weathering alternating with epochs of glacial transportation of debris can account for a great total of erosion.

There seems to be some tendency to minimize the amount of glacial planation in the Timiskaming region. Barlow[1] pointed out that the abrasion of ice scour had been greatly exaggerated, and that, in the region of lake Timiskaming, the depressions are not to be attributed to ice movement. He was referring specifically to the opinion that unaided ice scour had made lake Timiskaming valley; whereas it is known that the valley is of pre-Palæozoic origin, although deepened locally by ice abrasion. Wilson[2] says that the gorge-like valleys and canyons date from the post-planation period, and that these gorges are, in some cases, post-Glacial, but that most of them are pre-Glacial, and perhaps antecedent in origin to structural deformation, or possibly superposed. Evidently, he places the burden of gorge-cutting upon the time previous to the Ice Age. In the report of the same author on Nipigon basin[3] there are some statements specifically showing the last glaciation to have been insignificant as a factor in abrasion. Wilson says that there are no marked contrasts in profile curves between the parts which have been ice-eroded, and those which the ice could not scour. The diabase sheets characteristically form steep-edged cliffs,[4] and in many instances there

[1] Barlow, A. E., Geol. Surv., Can., Ann. Rept., vol. X, pt. I, 1897, p. 25.
[2] Wilson, A. W. G., Jour. Geol., vol. XI, 1903, pp. 660-662.
[3] Wilson, A. W. G., Geol. Surv., Can., Mem. 1, 1910, p. 113.
[4] It is to be noted that these diabase cliffs are not of the same class as those which have been started by the vertical or nearly vertical contact zones, discussed on pp. 13 and 14.

are piles of talus at the bases of them, but only in a few cases does talus reach to the top. From some cliffs which are glacially scarred, the talus is removed entirely, but at others, the talus remains partly buried under the sand-plains. Some of the talus piles are truncated near their bases by the ice action, but in some places in the lee of diabase cliffs the talus piles remain apparently unchanged, which shows that there was very little ice at such places. Nevertheless, for the most part, all the talus piles then extant were removed by the last glaciation. Wilson was not unmindful of the influence and duration of the interglacial processes, for he specifically assigns the cutting of at least one canyon to an interglacial date.[1] But it seems to the writer that he did not consider interglacial processes quite enough. The fact that the last glaciation left, a few sheltered talus slopes unstripped, is not a strong argument that nearly all of the talus was not carried away both in that epoch and in the preceding glacial invasions. The transportation of talus from the bedrock, and from the partly covered cliff faces must have been nearly complete in each ice advance.

The efficiency of cliff cutting is very great during alternating conditions of rapid, frost weathering action, and powerful transportation of debris. Efficient erosion is largely a matter of removal of the detached waste at the earliest possible moment after its separation from the bedrock. As regards erosion, the chief service of the glacial invasions was to carry away loose material that had been broken down already by weathering. W. D. Johnson[2] pointed out very clearly the difference between cliff sapping by glacial action, and abrasion by a moving glacier or ice-sheet. Abrasion is great when a glacier is moderately loaded with hard and angular drift and confined in a restricted channel, yet when the glacier is spread out as a sheet over a surface of slight relief, its corrasion is relatively insignificant. But even if its scouring effect is small, its transportation power, and its ability to pick up and pluck out masses of loosened rock are practically unimpaired. It is the contention in this paper that although glacial abrasion may have been relatively small in the Timiskaming region, other erosion by ice and frost action must have been very large. Although referring to mountain glaciation, Johnson[3] urged, "The upright element in the profiles, it would seem must be regarded as a sapping effect in which scour plays no part at all." In sapping processes frost work is active, it requires a sufficiency of precipitation, and temperature changes such that there is the most frequent possible change from melting to freezing, both of which conditions may be altogether independent of glaciers.

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[1] Wilson, A. W. G., op. cit., p. 126.
[2] Johnson, W. D., Jour. Geol., vol. XII, 1904, p. 573.
[3] Op. cit., p. 575.

However, the time preceding the advance of an ice-sheet, and the period following the close of glaciation provide favourable conditions for frost action, for considerable cliff sapping will be effected by the sheltered remnants of a retreating ice-sheet, and by the seasonal accumulations of névé at cliff bases during the rigorous climates which, in moderately high latitudes, probably precede a glacial advance.

If former periods following ice retreat were times of cliff recession, then at present there should exist examples of such action, and examples abound. Although there are some diabase cliffs which still bear glacial scars upon their fronts, thereby proving that there has been no retreat of the cliff since the withdrawal of the glacier, there are many talus piles which are surely post-Glacial in origin. This is explained by the fact that recession of cliffs is largely selective. Cliff recession is produced by such agencies or conditions as frost, jointing, contact metamorphism, or other natural weakness aided by an agent of transportation at the base, such as a large stream, a glacier, or a lake; and cliff recession is hindered by natural strength of the rock, and by a protective mantle of talus. Some cliffs which border sheltered shores are now in process of decay; talus is accumulating at the bases of the cliffs more rapidly than the feeble shore processes are able to remove it. Many a cliff is receding at one place and becoming covered with talus at another, depending upon its position with respect to a shore-line. Moon lake, 15 miles north of Blind River, discharges into Tendinenda lake through a narrow bay, and on the north side of this bay there is a cliff formed of a diabase sill intruding quartzite. The headland at the east end of the cliff is receding, but the main cliff facing southward and bordering the narrow bay, in which wave action is not vigorous, is half covered under the piling up of its own talus (Plate IB). Similar decadent cliffs border other lakes, such as parts of the Palisades of Tendinenda lake; but cliffs which form shore-lines exposed to vigorous wave action and ice shove are being cut back rapidly by sapping action. There must be thousands of such shore cliffs in the North Shore region, and their total annual recession is enormous.

Many cliffs away from lakes are breaking down rapidly. Quartzite cliffs seem very susceptible to gradual destruction. Near the north shore of Loon lake, lot 1, concession II, Merritt township, there is a great hill whose south side is completely covered with a steep fan of broken quartzite blocks. The blocks are rather cubic in their habit of fracture, and are, for the most part, about 6 inches in diameter. This is surely a talus pile which has grown so high that it has covered the original quartzite cliff face, and thereby stopped the recession of the cliff. Although this is perhaps a case of exceptionally rapid cliff retreat, it illustrates the activity of cliff recession since Wisconsin glaciation.

If, previous to an ice advance, the cliffs had accumulated great talus piles, then a condition of pseudo-equilibrium would exist, and the speed of weathering would be greatly decreased. Removal of the talus by an advancing ice-sheet would reinstate the cliff, after ice retreat, in a condition favourable for active recession. On the other hand, the ice invasion might cover the cliff faces, and bury the country with glacial drift; then superposed streams might be located across some former cliffs, and canyons would result from the recession of the consequent falls. A comparable case is mentioned by A. P. Low;[1] Bowdoin (McLean) canyon has developed below Grand falls on Hamilton river by headward cutting.

Still another means of interglacial erosion is the rather uncommon process of chrystocrene transportation, which has been described by J. B. Tyrrell.[2] Springs at the foot of a steep slope, by their alternate freezing and thawing, and by the assistance of gravity, move talus in large quantity and in massive pieces a considerable distance. This is mentioned here because such a process seems competent to have formed the great scree cone at the mouth of the hanging valley mentioned before.[3] Although this is not a spring, but a stream, and, therefore, not strictly speaking a chrystocrene, nevertheless its agency is essentially the same. As a stream, its velocity and volume both are too small to enable it to carry along large blocks of talus and to discharge them over the dump pile. But when it freezes, every boulder, large and small, is subject to the ice shove; so, aided by the steep slope, the small stream, little by little, moves a surprisingly great amount of waste.

Wilson,[4] quotes Low as authority for saying that in Labrador there has been cutting of post-Glacial canyons by still another process. Glacial deposits have dammed the old gorges, and rivers have cut new canyons in the bedrock, since the last glaciation. Although Labrador may seem rather far removed from the subject of this discussion with reference to the post-Wisconsin epoch, it is not at all improbable that similar conditions attained even greater development in the Timiskaming region during some of the much longer Aftonian, Kansan-Illinoian, Illinoian-Wisconsin, interglacial epochs.

Although ice scour may have been relatively slight, the other low temperature processes must have been very effective during glacial and

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[1] Low, A. P., Geol. Surv., Can., Ann. Rept., vol. VIII, pt. L, 1895, p. 301.

[2] Tyrrell, J. B., "Rock glaciers" or "Chrystocrenes," Jour. Geol., vol. XVIII (1910), pp. 552-553.

[3] See p. 13. The writer is especially indebted to Mr. F. B. Plummer for first-hand information on similar phenomena in the White mountains. Huntington ravine, about one-half mile east of Mt. Washington in the Presidential range of New Hampshire, affords a striking example of the movement of great quantities of large sized scree away from a fracture zone. In this case there is not even a small stream, nor is there watershed enough to provide more than an intermittent filling of the spaces within the scree pile with water; yet the movement has been considerable.

[4] Wilson, A. W. G., Jour. Geol., vol. XI (1903), p. 660.

interglacial periods. Their activity was greatly increased by association with fractured zones which made the rock inherently susceptible to breaking down into block talus. We know of at least three such interglacial epochs and four periods of glacial invasion.[1] These alterations of times favourable to cliff recession with periods of efficient removal of waste products are worthy of consideration as the major factors in cliff development and canyon cutting.

[1] If recent work in Iowa shall have confirmed Dr. Calvin's contention for an Iowan epoch, then we must add to the numbers of both interglacial and glacial epochs. The writer is indebted to Dr. M. M. Leighton for information upon this point which strongly suggests such a possibility.

CHAPTER IV.

STRATIGRAPHY.

Pre-Huronian.

SEDIMENTS.

Distribution.

The oldest rocks exposed in Espanola area are metamorphosed sediments. They appear in the northern part of the district along the Canadian Pacific railway, northwest of Espanola Mills, and in the northwest half of Hallam township.

Stratigraphic Relations.

The pre-Huronian gneissic granite, which intrudes these sediments and thereby serves, in most places, to mark the distinction between the Huronian and pre-Huronian sedimentary formations, is exposed only in the northwest corner of the area, where its relations to the old sedimentary rocks are obscured by faults and the overlapping lake sands. Although the evidence of difference is not clearly shown, the greater age of these pre-Huronian sediments is indicated by their very great metamorphism as compared with less alteration of the Huronian rocks which lie on them in the northern part of the area, and which in the south make up the greater part of the solid rock outputs of the region. The age relations are not indicated by the contact between the two series, for all the contacts observed are faulted ones. The difference in age is suggested by the unlike lithologic character of the formations. The pre-Huronian sediments are greywacke, and quartzite, and especially the metamorphosed equivalents of these rocks, chloritic, micaceous, and staurolitic and sericitic, quartzite schists, also hornblendic, and garnetiferous schists. The Huronian sediments are arkose, quartzite, conglomerate, limestone, and greywacke. In most places, the dip and strike of the Huronian rocks are easily determinable, but almost everywhere in the region, it is difficult to distinguish the bedding of the pre-Huronian sediments from their schistosity.

Character.

On the map accompanying this report the pre-Huronian formations older than the granite-gneiss are shown as divided into two divisions, the sedimentary and the igneous rocks. Most of the rocks are now extremely schistose, but many of them show their sedimentary character in spite of their metamorphism, and in a few places where they have escaped pro-

found metamorphism, they retain a distinctly sedimentary appearance. There are four main varieties of sedimentary rocks; micaceous slate or phyllite, micaceous schist, or greywacke schist, staurolitic schist, and quartzitic schist.

Micaceous Slate or Phyllite. This rock is exposed on both sides of Spanish river, just below the dam at Espanola Mills. It has a bluish grey colour on surfaces scoured by ice and water action, but where it is weathered, it appears dark green. It seems to have been deposited as a fine mud; it is an even-grained siliceous rock, which shows the marks of a hammer blow very plainly. It fractures readily along schistosity planes, exposing a gleaming micaceous surface. In the exposure below the dam, the rock is plainly banded. In most places it shows bands of about one-half inch thickness, and six such light streaks per foot of dark rock is about the average spacing. At the falls, the rock is both more finely and more coarsely banded. It shows a great deal of fine crumpling and many small faults of about 10 feet throw. There are many other faults of only one foot throw and less. The formation has been sheared and metamorphosed so severely that, being an incompetent but heterogeneous material, it has developed eye-like borders around stronger parts.

Micaceous Schist, or Greywacke Schist. This rock is very similar to the phyllite, but it seems to be more quartzitic. One might infer that it was originally a fine-grained sandstone which has been intensely metamorphosed, but the great development of sericite has changed it to a typical schist. False cleavage spoils the clean breaks usually found in schists, and sericitization has gone to such lengths that the rock is weak and tends to crush rather than split under hammer blows. Upon its fracture faces it shows the shimmer of colourless mica. A peculiarity of the schist is the development of mica phenocrysts, which are not oriented with planes parallel either to the true or to the false cleavage. They are distributed and oriented irregularly throughout the mass of the rock, and cut right across some of the schistosity planes. It is concluded that these phenocrysts, 3 to 4 mm. in diameter, are of later origin than the very fine-grained sericite which has made the rock schistose. These phenocrysts have been found only in a small zone north of the contact of the Huronian quartzite with the pre-Huronian schist, along the Algoma Eastern railway between Espanola station and Espanola Mills.

Staurolite Schist. This rock is an anamorphosed phase of the greywacke schist. It was seen only in the northeast part of Hallam township, and in lot 1, concession I, Shakespeare township. Twenty chains east of Webbwood station there is a staurolite schist which appears to pass by gradation through micaceous schist into the highly quartzitic schist which forms the hills north of Webbwood (see following paragraph). In

the southeast corner of Shakespeare township, the staurolite schist is well exposed. It is clearly a highly metamorphosed phase of the greywacke schist. In some places it looks much like an intrusive rock, and conforms closely to the description given by Coleman[1] of staurolite schist in the neighbourhood of Sudbury. In some places bedding lines have been preserved in spite of the great anamorphism and development of large (2 to 3 inches long) crystals of staurolite. Under the microscope, quartz grains 1 mm. in diameter are seen to make up the basis of the rock, but many secondary minerals have been developed around the quartz grains. Secondary mica and amphiboles are abundant, and there is some albite; but large crystals of staurolite, many of which are in cruciform twins, make up a prominent part of the rock.

Quartzitic Schist. This rock is quite different from the mica schists and slates. In colour it is greenish grey, and it is much sheared apparently parallel to the bedding. Although the rock is evidently quartzitic, it is marked by an abundant development of mica which is green on fresh surfaces and reddish brown on bedding planes. Because this schist has sheared into laminæ of the order of 40 to 50 per inch in thickness, it is a very weak rock; pieces one-tenth of an inch thick can be broken easily in the fingers. In some places it has a rather indefinite slaty cleavage, and in other parts it is more like ordinary quartzite. It looks fairly massive on weathered surfaces, but even in parts that are not schistose, freshly broken pieces reveal an abundant development of sericite. In the south part of Shakespeare township and in concession VI of Hallam township, there are high bare ridges of pre-Huronian quartzitic schist. The schist is highly quartzitic, and weathers with a gleaming white outcrop. Under the microscope it is seen to be almost pure quartz, with a considerable development of sericite. The quartz grains no longer have the equi-dimensional shapes common to constituents of clastic rocks, but they have irregular, crenulated margins, and the grains interlock. Many of the quartz grains show marked strained extinction, and elongated grains are arranged distinctly with the long axes parallel. There is no sign of the outlines or shapes of the original grains, but it is plain that the grains have had great secondary growth.

BASIC INTRUSIONS.

Into these sedimentary rocks there were intruded some rocks of basic nature. They are now metamorphosed beyond the possibility of determining their original composition, showing a marked development of chlorite and hornblende. A quarter of a mile directly north of Espanola station on the Canadian Pacific railway, there is a mass of

[1] Coleman, A. P., Ont. Bureau of Mines, Ann. Rept. vol. XIV, pt. III, 1905, p. 8.

basic, apparently igneous rocks on the south side of a small hill, and on the north side of it there is an outcrop of metamorphosed quartzitic schist. The south side of the hill rises in a low cliff from the sand flat, and the bare face of the rock is thickly speckled with pink garnets, which weather into little lumps upon the surface. The rock is largely of black hornblende with a considerable amount of quartz and black biotite. No feldspar is recognizable, but there are numerous phenocrysts of garnet as large as three-quarters inch in diameter throughout the mass. This is thought to be a pre-Huronian contact metamorphic development younger than the great diastrophism of that time, because similar mineral associations are not found in the regionally metamorphosed sediments of the district. On the east shore of Whiskey lake,[1] a greenstone which intrudes pre-Huronian schist is in turn intruded by granite. This suggests that the greenstone at Espanola is older than the granite which is found cutting the pre-Huronian sediments, and which seems to correspond to that which Lawson[2] called Algoman. In lot 12, concession VI, Merritt township, there is an intrusion of basic igneous rock which is thought to be pre-Huronian. It intrudes the metamorphosed sediments, and the contact zone is very much metamorphosed dynamically, although the interior of the mass is less obviously altered. There is a crinkly marginal zone around the massive part of the intrusion, in which the rock is gneissic. Under the microscope the essential minerals are discovered to be, 50 per cent hornblende, with a background of granulated, cataclastic quartz and feldspar. There are a few fresh-looking plagioclase grains, and much altered, larger crystals. Accessory minerals are large euhedral apatite crystals, some of which are broken, some biotite flakes, magnetite, and titanite. The texture is schistose, the hornblende crystals are hypidiomorphic granular, including irregular quartz grains and penetrated by them, all roughly oriented parallel with the biotite flakes. Another thin section collected from an outcrop on the border of lots 8 and 9, concession V, Hallam township, shows almost the same things, with the addition of glomerophenocrysts of titanite arranged in groups and in elongated collections.

GRANITE.

The northwest corner of the area includes a small part of a great granite mass which appears to extend a long way north and west of the region mapped. This is a pink gneissic granite so nearly free of ferromagnesian minerals that it might be called alaskite. The granite is coarse-grained, even near the chlorite schist which it intrudes. The

[1] Collins, W. H. Geol. Surv., Can., Mus. Bull. No. 8, 1914, p. 11.

[2] Lawson, A. C., Geol. Surv., Can., Mem. 40, 1913, p. 108. Lawson is followed by Miller and Knight in this nomenclature. Miller and Knight, Ont. Bureau of Mines, vol. XXII, pt. 2, 1914, p. 3.

border of the mass has an aplitic appearance, and the rock is grey. In places between the granite and the schist is a pseudo-conglomerate of granite boulders with a green chloritic matrix, apparently a crush breccia in a fault between granite and pre-Huronian schist. The contact is still further obscured by an injection of diabase, and by faults which bring the diabase into contact with the granite, and a remnant of Mississagi quartzite (see p. 25) into contact with the diabase. The Mississagi rock is green arkose, so typical in character that its identity is sure in spite of its isolated position. The granite seems to be younger than the diabase, although dykes of a similar basic rock have intruded it. Several schlieren of schist are exposed on the top of the granite mass. In the field, the granite appears to be massive, and not much metamorphosed, but under the microscope the constituent minerals show much shearing and fracture.

In addition to the normal pink granite, there are two different phases, one of which seems to be the border facies, a grey syenite, and a bright pink, aplitic alaskite. These rocks have been studied under the microscope. The normal pink granite has little ferromagnesian minerals. Essential minerals are 15 per cent quartz, 40 per cent oligoclase, 40 per cent orthoclase, and a little biotite, in hypidiomorphic granular texture. The feldspar minerals are about 4 to 5 mm. in diameter. An accessory mineral is zircon, and sericite and chlorite are secondary. The feldspar and quartz grains are strained and broken, they are granulated along shearing planes, and recemented with quartz and flakes of sericite; therefore, the rock is gneissic.

The syenite is a grey, massive-looking rock. The essential minerals, measured approximately, are 62 per cent orthoclase, 35 per cent oligoclase, and a little quartz. There are no ferromagnesian minerals in the thin section seen. The feldspar crystals are hypidiomorphic granular in texture, and they are saussuritized and chloritized. There is not more than 5 per cent quartz in this rock. It seems to be a bordering facies of the pink, gneissic granite.

The alaskite is an aplitic phase of the granite. The only minerals are orthoclase, oligoclase-albite, and quartz. The texture is cataclastic; almost all the quartz and feldspar are granulated into pieces which have regrown and cemented themselves together again. The feldspar crystals were originally rather large, for one fragment 7 mm. in diameter was measured under the microscope.

Age and Relations.

The granite intrudes schist, associated with quartzitic schist, both of which are much more metamorphosed than the Huronian quartzite, and are, therefore, regarded as pre-Huronian. Near the granite, there

is an outcrop of fresh-looking Mississagi arkose, markedly less metamorphosed than pre-Huronian quartzite. The Mississagi arkose appears to have been derived from the granite, but the pre-Huronian quartzite is almost free of feldspar, although the abundant sericite probably contains elements formerly constituting feldspar. The nearest other outcrop of Mississagi quartzite is 5 miles south of the granite, and at that distance from the granite it is not more metamorphosed than the outcrop close to the intrusion. Obviously, the granite did not intrude the Mississagi arkose, and it did intrude the highly metamorphosed quartzite and schist. The gneissic texture of the granite shows that its intrusion was succeeded by regional deformation; thus, before the Huronian period, there was a period of great diastrophism, during which the pre-Huronian sediments—greywackes and quartzites—were steeply folded and intruded by granite, and then there was further deformation before the accumulation of the Mississagi arkose.

Huronian.

After their deposition, the pre-Huronian rocks were intruded by igneous rocks, deformed, and were subjected to a very long period of erosion.[1] The rocks of the Bruce series accumulated upon a peneplained surface, developing a normal basal conglomerate. In the Espanola area, this contact is not shown; every one of the contacts between the Bruce and the pre-Huronian series found is a fault contact. Collins[2] mentions one place in the area, within 10 feet of the pre-Huronian schist, in which there is a peculiar arkose, rich in dark minerals. Possibly the Bruce series originated from the underlying mica schist of the pre-Huronian series by the same process of disintegration as that by which the basal arkose in Whiskey Lake and Blind River districts was derived from the granite gneiss beneath it. If the contacts here are faulted in every case, the occurrence of black mica is less significant than it would be otherwise; nevertheless, there is little doubt that this rock is derived largely from the pre-Huronian rocks. Close to the micaceous schist described above, which is found along the Algoma Eastern railway between Espanola and Espanola Mills, there is a large ridge of conglomeratic quartzite, which is thought to be the basal conglomerate of the Bruce series. Within 50 feet of that schist, which is marked by mica phenocrysts and light coloured mica only,[3] there is an unusual development of black mica in the quartzite. Besides the biotite, there are numerous pebbles of vein quartz and of pink granite, evidently not of local origin. In the next chapter the evidences of a large fault between

[1] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, pp. 19-21.
[2] Collins, W. H., op. cit., p. 14.
[3] See page 20.

the pre-Huronian and the Bruce series are presented, and the conclusion is stated that the Huronian rocks have been thrust over upon the pre-Huronian terrane. It is certain that the Bruce series is younger than the rocks which have been called variously, Sudburian, Timiskamian, and here pre-Huronian, although Lawson[1] states that the Bruce series is probably older than the Sudburian series.

BRUCE SERIES.

MISSISSAGI QUARTZITE.

Distribution.

As shown in the geological table on page 7, the base of the Huronian rocks consists of the Mississagi quartzite.[2] In the Espanola area there are rather extensive outcrops of quartzite and conglomerate which are thought to be correlated correctly with the Mississagi quartzite. They lie in three bands, two partly across the area, and the other one from the southwest corner to the northeast part. The largest band is not a continuous outcrop; the conglomerate and quartzite appear in detached hills which stand up above the sand-plain. The hills resemble islands rising from a lake, and such they were in Pleistocene time. The northerly outcrop of Mississagi quartzite is bordered on the north edge by a conglomeratic phase, and it seems to have been thrust against and upon the pre-Huronian formations. In the southern part of Merritt township, there is another outcrop of the same kind of rock, but the conglomeratic phase is absent from the surface. This outcrop has fault contacts on the northern side, and is bounded on the south side by the formation which overlies it stratigraphically, the Bruce conglomerate. The fault brings this outcrop into contact with another Mississagi quartzite area in Hallam township, and eastward it pinches out about halfway across Foster township. The third outcrop stretches across the southeastern part of Foster township, where it has been exposed by another thrust fault, and brought into contact on the northwest side with the Serpent quartzite and with the Espanola greywacke. (The Serpent quartzite is the youngest member of the Bruce series, and the Espanola formations lie immediately below it; see the geological table, page 7, and descriptions of these formations, pages 36 and 38.)

Character.

In the northern outcrop, the conglomeratic phase is distinct. A good exposure lies about 20 chains west of the Algoma Eastern railway along the trunk road near Espanola, and there is another, equally good,

[1] Lawson, A. C., Bull. Dept. Geol., Univ. of Cal., vol. 10, No. 1, 1916, p. 14.
[2] Collins, W. H., op. cit., pp. 17-19.

about 2 miles south of Webbwood between the two roads which lead to Lee Valley. At each place, the conglomerate forms a high hill. The exposure near Espanola is a very vitreous quartzite showing scarcely any evidence of bedding and including scattered pebbles of quartz and granite. In different places the groundmass is coarse, gritty quartzite, and fine-grained quartzite. Boulders of granite are much rarer than pebbles of granite at the south end of the hill, and they decrease in number towards the north. At the north end of the hill, there are not even pebbles to be seen. On fresh surfaces, the quartzite has a dark, steel-grey colour, weathering to a darker shade. The rock weathers in a peculiar way; the granite is less resistant than the quartzite, and there are depressions in the quartzitic matrix, from which the granite pebbles have been removed by weathering. This is strikingly different from the behaviour of the supposed tillite, which is described on pages 43 to 48 of this report. In that case, the matrix is less resistant than the granite boulders and the boulders stand out in relief from their background. Probably the boulders in the basal conglomerate were partly disintegrated at the time of their deposition, whereas, in most cases, those in the other conglomerate are still fresh. Also the quartzitic matrix of the Mississagi conglomerate is not readily soluble, but the basic, and in places, calcareous matrix of the younger conglomerate is quite apt to be dissolved markedly. In the cut on the Algoma Eastern railway mentioned before, there is a good exposure of the Mississagi conglomerate, where the conglomerate is biotite-rich as described in connexion with the fault.[1] The pebbles are small and scattered; quartz, schist, grey granite, and greywacke specimens have been noted among them.

The quartzite proper is rather variable. In some places it is coarse-grained, arkosic, and cross-bedded, in other places it seems to be highly quartzitic, and so much recemented that the original grains cannot be told apart by megascopic inspection. In lot 10, concession IV, Merritt township, the quartzite is very fine-grained, dense, and massive, but the individual grains are distinguishable. Every 4 to 6 feet, there is a sericitic parting which has been dynamically metamorphosed. By the weathering of these sheared bands the exposed quartzite surfaces are deeply rutted. In other parts of the same outcrop the quartzite is very vitreous, and looks like almost pure silica, except that upon the weathered faces feldspars show. This rutted type of surface weathering is to be seen also in the other quartzite outcrops between that locality and the hill in lots 1 and 2, concession VI. On the south side of the last mentioned hill, the quartzite is so much metamorphosed that the individual grains are indistinguishable. The quartzite seems to be more coarse-grained, free of

[1] See page 24.

feldspar, and cross-bedded towards the top of the formation. This seems to be true also of the outcrops which border the south bay of Apsey lake.

In many places, the quartzite has a distinctly green cast, and in others, the small iron content has oxidized to hematite which gives a pale purple colour to the bedding planes. This characteristic is of use in identifying outcrops.

In certain places, the quartzite has been badly fractured and the openings have been filled with quartz veins. In lots 1, 2, and 3, concession VI, Foster township, the quartzite is much fractured and irregular in strike. Most of the quartzite is not distinctive in type; some of it appears to be rather pure quartz and some of it seems to be arkose. There is a high knob southeast of the debouchure of lake Wabagizig, of coarse-grained, cross-bedded, and lenticularly arkosic material which has been brecciated and filled with quartz veins. The great resistance of the quartz veining seems to have caused it to stand up above the surrounding quartzite as a hill. Similar quartzitic complexes are found along the north shore of lake Stratton, and in the neighbourhood of Hicks mill in Hallam township.

In other places, the quartzite has a sandy facies, the grains are distinct, and there are well-defined, dark coloured, bedding lines. This facies has a dark colour in some places, and it grades into quartzitic greywacke which is decidedly developed near the contact with the overlying Bruce conglomerate in lots 7 and 8, concession V, Foster township. In many places, the quartz is very feldspathic and of saccaroidal texture, it weathers into a pale pink, flesh coloured rock, so even grained, smooth surfaced, and opaque, that it resembles porcelain; such a type is on the shore of lake Panache, southwest of the island which is crossed by the eastern boundary of Foster township. Near the same place, much of the quartzite is marked by extremely thin coatings of red hematite between bedding and other planes of opening. In some places cracks are filled with a black specular hematite. In certain parts, the quartzite has unusual facies; for instance, at the point north of the old camp on the south shore of lake Wabagizig, there is quartzite which is distinctly laminated, olive green in colour, with layers of greenish yellow, sandy, fine-grained arkose.

A characteristic type of Mississagi quartzite is one made up of irregularly bedded, coarse, clear blue quartz grains, about one-eighth inch in diameter. This characteristic and a greenish colour are useful criteria for the recognition of the formation in the North Shore region.

Microscopic examination shows that the matrix of the conglomerate consists of an impalpable sericitic matrix containing little angular chips of quartz and microcline 0·5 mm. in diameter, larger grains of quartz

and quartzite as much as 3 mm. in diameter, and some rounded grains of microcline. Within the conglomerate, there are many pebbles, including one of quartzite made up of fragments and rounded grains of quartz and microcline. This is not like the pre-Huronian quartzite already described, and it suggests that another quartzite was deposited before the Bruce series, and exposed to erosion before the Huronian formations were deposited. A granite pebble appears under the microscope to be part of the pre-Huronian granite already described.

Under the microscope, the quartzite is seen to be mainly quartz, with a few grains of feldspar, and flakes of sericite. In the less typical, greywacke phase of Mississagi quartzite, there are, in addition, some flakes of biotite, and scattered hematite or other ferrite dust. The quartz grains are rounded roughly, and surrounded with smaller pieces of quartz with "suture" outlines. Many of them have grown together into very irregular crystallographic units, with branchiate and crenulated margins, but this secondary reorganization of the quartz fragments is not so marked as in the pre-Huronian quartzitic schist.

Thickness.

The thickness of the basal conglomerate seems to be considerable in the Espanola area, but the very indistinct bedding of the deposits renders any close figures impossible. The true quartzite part of the formation must be at least 4,000 feet thick, although these figures have been increased to an indeterminable extent by the shearing together of the formation under thrust.[1]

Origin.

The basal conglomerate is thought to be of subaerial origin. The reasons for this conclusion are, that it shows great physical and petrographic heterogeneity, its matrix is highly quartzitic, not argillaceous, and it carries granite pebbles and small boulders which appear to have been partly weathered at the time of their deposition. The upper part of the Mississagi formation which is well stratified, cross-bedded, and of well sorted sand, appears more like the shore deposit derived from a land area of considerable relief.

BRUCE CONGLOMERATE.

Stratigraphic Relations.

Above the Mississagi quartzite lies the Bruce conglomerate. The plane of contact is quite sharp and distinct, and slightly irregular in contour. At most exposures, there is an abrupt change without gradation

[1] Chamberlin and Salisbury, Geology, vol. II, 1904, p. 62.

from clean quartzite to very gritty, pebbly, and cobble-rich conglomerate. But there are places in which there is an appearance of alternation; at one place three quartzite layers alternate with thin beds of conglomerate, and 5 feet below the supposed true contact is a 1-foot bed of greywacke conglomerate. Almost on the line between lots 5 and 6, concession V, Foster township, a place was found where the rock had naturally broken along the plane of contact between the Mississagi quartzite and the Bruce conglomerate. The surface of the quartzite beneath the conglomerate is rough but not ragged, relatively plane, but not smooth or polished; it is rough rather than smooth. The break between the Mississagi quartzite and the Bruce conglomerate is abrupt and positive; there is no introductory change within the quartzite at this place. Nevertheless, in the north half of lot 8, concession V, of the same township, there is a discordance of dip within the quartzite of 22 degrees, above which the quartzite grades into a sandy weathering, quartzitic, almost black rock, which in turn grades into a conglomeratic quartzite. The conglomerate gives place again to white, arkosic quartzite which is conformable apparently below massive, quartzitic conglomerate, in which there are boulders of granite, and pebbles and angular pieces of quartz and quartzite. In one place a "soled" quartzite boulder 14 by 8 inches in diameter is half embedded in the matrix. In this place the contact appears to be sharp and clean cut, but within ten paces to the east, bedding lines within the conglomerate are parallel in dip and strike with those in the quartzite dipping beneath them. It is not plain that the quartzite inclusions in the conglomerate are derived from that quartzite which happens to underlie it immediately. On the other hand, it is more probable that most of the quartzite pebbles and boulders found in the Bruce conglomerate are older than the Mississagi quartzite. One quartzite looks much like another, and probably there were several quartzites older than the Bruce conglomerate. Therefore, the presence of quartzite in the conglomerate does not prove that the Mississagi quartzite was eroded before the deposition of the conglomerate. But a proof of unconformity is the fact that the contact of the conglomerate cuts the strike of the quartzite at a low angle.

Distribution.

As Professor Coleman reported, in Merritt township the conglomerate covers the top of the escarpment which roughly follows a line parallel to lakes Griffin and Tulloch, and about one-quarter mile north of them. In the west end of the outcrops, repetitive faults have caused a peculiarly irregular distribution of the formation, and, farther west, its non-appearance at the surface. Northeast of lake Tulloch the formation is interrupted and partly displaced by a diabase intrusion, but it outcrops

between Brazil lake and Vermilion river, and on the west side of Brazil lake. Although interrupted and displaced by numerous faults and igneous injections, and partly hidden beneath drift and swamp, the conglomerate is traceable right across Foster township. On a point straight south of the narrows in lake Apsey, in Merritt township, there is another small outcrop of the conglomerate, which borders a fault. the fault can be found on the other side of the lake and traced intermittently westward to the north side of the diabase hill in lot 11, concession III, where there is another small outcrop of the conglomerate. This outcrop was not traced eastward, but its continuation seems to be among certain irregular patches of conglomerate about the narrows of Loon lake. These outcrops seem to be related also to another fault which is shown by a small, greatly sheared area of conglomerate in the southwest corner of the south bay of Apsey lake. Westward, this fault is shown by the outcrop of conglomerate near the north line of lot 1, concession I, Hallam township. These outcrops of conglomerate are useful as a means of locating the faults. The faults are very difficult to detect, because a quartzite is faulted against quartzite and both formations are nearly vertical in position, and much sheared parallel to the bedding. In lot 5, concession I, Hallam township, conglomerate crosses the boundary of the township and continues northeastward into Merritt township; there it lies in a band a little north of the north line of concession I, as far as lake Apsey, beyond which it can not be traced. Striking almost northeast, another band of conglomerate extends from a place south of the southeast end of lake Stratton to the most westerly bay of lake Panache. This occurrence is cut out in places by a complex of faults and folds almost parallel to the strike of the rocks. The last outcrop to be mentioned cuts across the southeast corner of Foster township, crossing the township lines about one mile north and one mile west of the township corner.

Character.

In all these outcrops the character of the conglomerate is essentially the same. It is a boulder and pebble conglomerate, massive in some places and roughly stratified in other parts. The conglomerate, on an average, carries about five boulders ranging in size from 6 inches to a foot in diameter for every 100 square feet of exposure. Cobbles from 4 to 6 inches in diameter are as plentitful as one to every square foot, and pebbles up to 3 inches in diameter are about six to a square foot. For the most part, the boulders and pebbles are either pink or grey granite, quartz, and quartzite, but there are some conglomerate pebbles, and a few of schist. The matrix is very gritty, a great number of small quartz grains from pin's head size to pea size are scattered through a dense,

dark green matrix. Commonly there is a sort of rough bedding in the conglomerate. It does not show thin bedding lines or laminations, but massive stratification which shows especially clearly on weathered faces of the rock. The conglomerate is very irregular in its structure, in some places it is strikingly massive, and in others distinctly bedded. In the massive type, the matrix is drawn away from the pebbles, leaving open spaces around them. The reason appears to be that the formation has been considerably sheared in most parts, and in the process, the pebbles broke away partly from the matrix. Evidently, under the impressed stress, the more plastic groundmass flowed enough to leave a space around parts of the resistant pebbles. Many of the spaces are now filled with calcareous matter and metallic sulphides; possibly the calcareous deposition was the earlier, and precipitated the sulphides from intruded acid solutions, which would account for the present association. Upon exposed faces, the calcium carbonate is dissolved, and the spaces remain, causing a peculiar, cracked appearance in the conglomerate. In other places, the matrix is not calcareous, but quartzitic, and there are quartzite layers and lenses in the conglomerate member. Beds of quartzite are found in all the bands of conglomerate.

Under the microscope the conglomerate reveals different facies, as it does megascopically. A thin section taken within 6 inches of the bottom of the formation is very rich in biotite and colourless mica, the quartz grains are rounded and irregular, with secondary growth resulting in crenulated or suture outlines, and the feldspar grains are much altered. A thin section taken from a quartzitic type of the conglomerate shows both rounded and angular quartz fragments, with a few fresh-looking plagioclase grains, and some much altered grains of other feldspar. About a quarter of the rock is very fine-grained, indeterminable, groundmass. A thin section taken 20 feet below the top of the formation shows a similar composition of angular and rounded grains of fresh plagioclase and quartz, and grains of weathered feldspar and weathered granite, in a matrix of very fine-grained argillite, with numerous flecks of opaque clay-like material. Near the top of the formation, the boulders are less numerous, and the matrix is very fine-grained. A thin section taken within 2 inches of the overlying formation shows scattered, angular grains of quartz and altered feldspar in a very fine-grained matrix, with much chlorite and sericite.

A quartzite member, 25 feet thick, found 20 feet below the top of the formation, contains much carbonate of undetermined composition. It is made up chiefly of rounded quartz grains, fresh looking albite, and altered orthoclase grains. The cement is composed of quartz which connects little grains of quartz and feldspar. The quartzite seems to have been partly porous, for cavities which were apparently original

with the deposition of the sand grains are now filled with some carbonate mineral of high optical relief, probably an iron-bearing dolomite.

Origin.

The included beds of quartzite suggest that the conglomerate was deposited, at least in part, by water action. The massive character of the deposits, and the heterogeneity of the individual inclusions testify to the lack of any consistent sorting process. In origin these deposits seem to be continental rather than marine. From their general characters they are thought to be either glacial outwash, or else of subaerial origin in a semi-arid climate. The former is the view favoured by Coleman, in support of which he cites a place where the conglomerate lies on a supposedly glaciated, smooth surface of quartzite. He emphasizes also the irregular contact of the two formations. He was of opinion that the conglomerate lies on the truncated edges of the quartzite. The Mississagi quartzite,[1] Coleman[2] took to be the Sudbury quartzite, and he tentatively correlated the overlying conglomerate with the Cobalt conglomerate. But the more intensive work which has been done since in this region does not support this correlation. The contact is not nearly so irregular as was thought, for the conglomerate lies on the quartzite with no apparent discordance of dip. The distribution of the outcrops of the formations also shows a near conformity. The glacial view suffers from the lack of discovery of striated boulders, and from the absence of anything which is strongly suggestive of a clay matrix carrying fresh-looking foreign boulders, and the surface of the quartzite beneath the conglomerate, described on pages 28 and 29, does not resemble a glaciated surface.[3]

The matrix is very gritty, not argillaceous, and might well be the slightly sorted residuum of weathered igneous rocks. Its character suggests that it may be an alluvial deposit which has accumulated at the base of a steep slope in a region of little rainfall. But alluvial deposition upon such a well sorted shore deposit as the Mississagi quartzite requires distinct uplift. In harmony with such an uplift, the conglomerate should be followed by the normal sequence of sandstone, shale, and limestone; but the irregularities in the underlying quartzite and its great thickness suggest that the adjacent land area was high already. After a postulated, second elevation, there would be a repetition of copious deposition of coarse sands. The Bruce conglomerate is followed by a thin streak of fine-grained argillite and 150 feet of limestone, which makes the supposition of uplift very improbable.

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[1] Collins, W. H., op. cit., p. 18.

[2] Coleman, A. P., Ont. Bureau of Mines, vol. 23, 1914, p. 221.

[3] This was the only ancient surface of the quartzite seen by the writer. Other surfaces if they could be found, might not look similar.

The stratigraphic position of the conglomerate suggests that it may be of glacial origin. Now, the Bruce conglomerate is a *xenoclastic* conglomerate, that is, it contains materials unlike the rocks upon which it rests; many of these materials have been transported considerable distances. The normal stratigraphic relations of a xenoclastic conglomerate are, an unconformity below, and a gradation into coarse sandstone above. It differs from most intraformational conglomerates, because the latter are made up of small transported fragments of the underlying rock, and in nearly all cases, they are thin layers of broken up and slightly rounded, autoclastic materials. Thin conglomerates within a sandstone are not rare, because both are related phases of the same type of deposition, but a xenoclastic conglomerate lying upon hundreds of feet of fine, well laminated argillite, and followed by equally well sorted material, suggests some unusual agency of deposition. An ice-sheet or other glacier deposits xenoclastic conglomerates with stratigraphic relations otherwise anomalous, and it is suggested that this may be nearly as critical a test as the finding of glaciated pebbles. Such stones, in any considerable numbers, are regarded as proof of a glacial origin, because no other process is known which causes this kind of striations, and because present glaciers scratch their inclusions. Similar criteria may be applied to the stratigraphic relations of conglomerates. Present glaciers drop their loads quite irrespective of the character of the underlying rocks, indifferently, in water, at the shore-line, and inland, and no other agency except ice so distributes thick xenoclastic conglomerates.

The Slate[1] conglomerate (Gowganda formation) of the Bruce Mines area shows both these criteria, striated stones have been found, and its stratigraphic relations are anomalous; therefore, arguments in favour of a glacial origin are strong. But the conglomerate at Espanola called Bruce conglomerate is not nearly so clearly of glacial origin, because no glaciated pebbles have been found, and there is an angular unconformity beneath the conglomerate, which is in harmony with the suggestion that it may be of alluvial deposition. The overlying formations, fine-grained greywackes and limestones, apparently conformable upon the conglomerate, with no transitional, beach-like deposit beneath them, are hard to explain whether the conglomerate be alluvial or glacial in origin; and only the xenoclastic composition of the conglomerate is in harmony with a glacial origin. It is thought that the Bruce conglomerate at Espanola is an alluvial accumulation, but its origin is not determined.

ESPANOLA GROUP.

The Espanola group consists of three formations, a limestone formation at the base, a fine-grained greywacke and slate, and a thin

[1] Collins, W. H., loc. cit., pp. 21-22.

calcareous formation about 300 feet above the lower one. The lower limestone is called the Bruce limestone, and the upper one is known as the Espanola limestone. The middle formation is called the Espanola greywacke, because in most places it has no slaty cleavage, and in some places it is too coarse in texture to be called slate. The limestone formations are useful stratigraphic markers in this series of conglomerates and quartzites, and for that reason it has been the practice to distinguish carefully, wherever possible, between the two formations.

The group is exposed in two irregular bands across the area. The formations lie upon the Bruce conglomerate, and border those outcrops on the south. The soft and somewhat readily soluble nature of the rocks of the Espanola group has resulted in their deep erosion in many places where they are at the surface.

Bruce Limestone.

Stratigraphic Relations. Above the conglomerate there is a limestone formation with about 6 feet of shaly greywacke, or argillite, between them. The contact between the conglomerate and the greywacke is well defined, but not evidently an unconformity. The contact was seen in only two places in Merritt township, one along the north side of the railway on the line between lots 3 and 4, concession IV, and the other on the west side of the gully in the northern half of concession III, near the line between lots 9 and 10. Also, in Foster township, on the west shore of Brazil lake, about half a mile south of the north end of the lake, the contact is exposed. In every other likely place examined there is either a fault contact between the conglomerate and the limestone, or the contact is drift covered.

Distribution. The best outcrop of the limestone in Merritt township is on the south side of the road, about one-quarter of a mile west of the mill on Apsey lake. Another thick exposure is in the gully mentioned above, about one-quarter of a mile north 30 degrees west from the other locality. Exposures in Hallam township are poor, but in Foster township there are good ones. The outcrop on the west side of Brazil lake is fairly clear (Plate II A). Another good exposure is on the west side of a narrow bay which leads out of the southeast corner of Stratton lake. Here and there along the fault on the south side of the Bruce conglomerate scattered fragments of the limestone show, and in a few places the combination of faults and basic intrusions has overturned the series, locally, in such a way that limestone lies on the north side of the conglomerate, but these cases are rare. The outcrops are hard to find, and in many places, on account of the faults and drift covering, the formation does not come to the surface.

Character and Thickness. In the Espanola area, the limestone has been found 150 feet thick, but in most places the fault has decreased its visible thickness, and its outcrops nearly everywhere are covered by soil or swamps. It is a red-weathering formation, and markedly thin-bedded. Its surface is lined by the alternation of more with less siliceous layers. In some places the rock is white marble, which effervesces freely in acid, but for the most part it is decidedly siliceous. Under the microscope the rock is seen to be almost 80 per cent calcite, and 20 per cent very fine quartz grains. Other layers within the limestone formation seem to be almost free of calcite and to consist almost entirely of very fine grains and chips of quartz and little flakes of sericite. This different mineralogical composition results in the characteristic, lined, weathered surfaces.

Origin. The thin bedding of the limestone, and the many siliceous layers suggest that much of it was deposited in shallow water near a shore. The original structure of the limestone has been obliterated by intense metamorphism, and its original thickness probably has been reduced by leaching of the relatively soluble carbonates; thus the exact conditions of its deposition are unknown.

Espanola Greywacke.

Stratigraphic Relations and Distributions. Conformable on the Bruce limestone there lies a formation of greywacke, consisting of an interbedded series of calcareous and siliceous argillites. This greywacke formation is not conspicuous in the area, because for the most part it is at the bottom of a swamp or some other depression. It is well exposed on the north shore of Griffin lake, and at about 16 chains along the track north from Merritt station.

Character. In many places the beds are little more than laminæ; most of them are between one-fourth of an inch and one inch thick. The weathered surface of this formation is very rough and deeply lined, because the calcareous layers are much more soluble than the siliceous ones, and a grooved surface results. In semi-arid climates a less well cemented formation weathers in the opposite way; the calcareous layers are resistant,[1] whereas the sandy layers are freely eroded by the scour of the wind. However, in the Timiskaming region, the Pre-Cambrian, firmly cemented rocks weather according to their relative solubilities.

In nearly all outcrops the true character of the rock is difficult to discern. The formation is incompetent to withstand thrust forces, and

[1] The Killdeer mountains in North Dakota furnish striking examples of weathering which is the antithesis of that found in the Espanola greywacke. There the rocks are middle Tertiary in age, and probably of very shallow water and partly subaerial deposition. The composition of the two formations is strikingly similar, but in semi-arid, western North Dakota, the limy layers are resistant, and the siliceous bands have been scooped out from between them.

crumples readily under compression; consequently the outcrops are peculiar. The siliceous beds are brittle and relatively resistant, whereas the calcareous layers are relatively plastic. Under the great compressive deformation which has affected the formations in this area, the greywacke member crumpled into small folds. This folding caused the siliceous layers to break into pieces, and further deformation forced the plastic calcareous material around the resistant siliceous portions in a very strange manner.[1] The weathered surface of such a deformed member has a peculiar, pitted appearance; the more soluble calcareous layers dissolve the more easily, but they have been squeezed and broken out of all semblance to alignment, so that the pits and cracks have no orientation and no orderly distribution.

Thickness and Origin. The metamorphosed condition of the formation renders an accurate measurement of the member impossible, but it is estimated to be about 280 feet thick. It is thought to be a shallow water deposit, probably estuarine in origin.

Espanola Limestone.

Stratigraphic Relations and Distribution. Both upper and lower contacts of the Espanola limestone are gradational into greywackes. The lower transition consists of an interbedding of dark green, almost black greywacke layers with pale greenish limestone. Its distribution at the surface is wider than that of the Bruce limestone, apparently because the fault between the calcareous members and the conglomerate is one of small throw, and in very few places involved the upper of the two limestones, whereas in most places, it left the lower one unexposed. Good exposures are to be seen on the north shore of Griffin lake where the outcrop lies across the large point, and on the west side of the road leading northward from the mill on Apsey lake, about 35 chains from the mill. Outcrops of this greywacke show here and there along the line between the conglomerate and the greywackes in both the northern and the southern exposures.

Character. The limestone layers vary in thickness from one-tenth of an inch to one inch. They are not persistent in distribution, nor regular in spacing; in many cases they are lenticular. In some places the layers are quartzitic, and nearly everywhere, siliceous. The limestone is less pure than the Bruce limestone, and not nearly so thick. It weathers to a noticeable reddish brown colour, and in a few places to a bright hematitic red. It is not very readily weathered in spite of its calcareous content, and for that reason, and on account of its red-coloured outcrop,

[1] Compare the folding of brittle and soft layers contrasted in jasper. Leith, C. K., "Structural geology," 1913. fig. 52, p. 108.

it is easier to trace than most limestone members. It seems to owe its resistant qualities to the product of its weathering, an insoluble residuum of ferric oxide.

Although the formation is irregular in texture for the most part, certain outcrops by the shore of Griffin lake show a composition of notable homogeneity. Near the water level and close beside the water's edge, the limestone member dips 78 degrees south. The lake water, which the waves splash upon the rock, dissolves hemispherical holes ½ to 3½ inches in diameter, and as deep as 6 inches. The outcrop has a strangely jagged, and honey-combed appearance, due to the coalescing of many of the hemispherical holes. Such pits are formed under a peculiar set of conditions. The water splashes upon the limestone, and any little irregularity in the surface serves to catch a few drops, but most of the rock remains free of water after the surplus has run back into the lake. The water in the little holes dissolves as much calcium carbonate as it is able to hold, which indeed is very little; however, another wave throws fresh water upon the rock and into the depressions, replacing the saturated solution with pure solvent, and so the process continues. The greater the hole which has been dissolved, the larger the amount of solvent it will catch, and the faster solution proceeds. The speed of solution is increased not only because there is more water in a large hole than in a small one, but because the ratio of volume to surface increases with the increase of radius of a sphere. In those places where the rock is heterogeneous, the surface is lined with the alternation of soluble and less soluble layers, and the holes grow into grooves, but where the rock is very uniform in composition, the surface of solution is likely to be spherical. Why the holes are hemispheres rather than fortuitous shapes is because an uneven surface of a homogeneous solid dissolves more readily than a plane surface, much in the same way, and for the same reason, that large crystals grow at the expense of little ones. Points and edges are places of molecular instability; therefore, any irregularities which might have been in the little hole at the beginning tend to become removed by solution. Thus the surface of a hole in the homogeneous limestone grows by solution, and because solution is fastest where it is easiest, it tends to remove first, points, edges, and angles. The ultimate result of such a process is a spherical surface, because a sphere is the only shape which provides equal chances of solution over all the surface, and it is, therefore, the most persistent shape. If we suppose any change in shape from the spherical, some part must come into such a position that solution will remove it faster than other portions, and the change in shape resulting from such selective solution will be back towards the sphere. A spherical solution surface is one in which every point is dissolving just as fast as every other point,

so that the surface is a perfectly balanced, stable form. Thus, the hemispherical holes depend upon the presence of a homogeneous, soluble rock, by the side of water which has a fairly constant level, and a rock surface of such configuration that there is an intermittent, but repeatedly renewed, supply of solvent, without appreciable abrasion.

Some of these rather fragile solution features have not been affected by the yearly ice shove, although they border the water; but others have been truncated by ice scour, and now indent a smooth surface (Plate II B). Those that affect an almost level surface have escaped destruction, for the ice around a lake rides over a low slope without causing any marked abrasion, much as glaciers have advanced over nearly flat country without removing all the old soils.

Thickness and Origin. The formation varies in thickness, from 1 foot to as much as 25 feet. In spite of its thinness, it is a useful means of correlation. The homogeneous part surely was deposited in still water, and the formation as a whole seems to represent a slight retreat of the shore-line.

SERPENT QUARTZITE.

This formation consists of two different members which grade into one another. The base of the formation is fine-grained greywacke and the top is coarse arkose. The whole formation seems to record a retreat of the sea.

Greywacke Member.

Stratigraphic Relations and Distribution. This member seems to be transitional between the calcareous formations and the overlying quartzite. The base is another interbedding of thin calcareous and siliceous layers, very similar indeed to parts of the Espanola greywacke. Characteristic outcrops are along the railway a few chains south of Tulloch lake and at Merritt station. In both localities the rock is of the more quartzitic phase, and not badly crumpled. On the north shore of Anderson lake and on the west side of the north arm of Apsey lake, the characteristic pitted appearance of the crumpled calcareous and quartzitic material is well exposed.

Character. Remarkable features of the upper greywacke are its ripple-marks and mud cracks (Plate III A) which are very well preserved in thin greywacke layers between thicker layers of nearly clean quartzite. Such may be seen beside the railway just south of Tulloch lake, and again at Merritt station. The quartzitic phase clearly has the preponderance in the upper part. It is blue grey with thin, dark bluish greywacke layers showing mud cracks and cross sections of irregular thickness. The formation weathers rapidly by the conversion of the

pale streaks into limonitic clay, whereas the dark layers remain as outstanding ridges. The whole formation seems to be somewhat calcareous, and certain of the lower layers are limestone. The dark bands vary in thickness, from one inch to a small fraction of an inch, and the light bands are from 1 to 6 inches thick; in some places light and dark layers one-tenth of an inch thick alternate for a few feet. The dark layers are fine-grained argillite, and the light bands seem to be very fine siliceous material.

An unusual and widespread feature of this formation[1] is the presence of pebbly quartzitic dykes cutting it (Plate III B). They are on the east shore of Griffin lake, on the most easterly shore of the north arm of Apsey lake, and on the south shore of Augusta lake about 25 chains southeast from the east end of the portage between lakes Elizabeth and Augusta. The last mentioned dyke is not in the greywacke member, but in the arkosic quartzite which overlies it, and the dykes on Apsey lake are in Espanola greywacke. A conglomerate dyke, like the others, cuts the quartzite surrounding the long narrow lake which is almost in the middle of the north boundary of that part of Nairn township included in the accompanying map. This dyke is 35 feet wide, it can be followed for 6 chains, and the bearing of its outcrop is due north. It carries granite and quartzite pebbles and cobbles (rounded stones as large as 3 inches and not greater than 6 inches in diameter). Most of the dykes are from 3 to 10 inches wide, and are formed of material like parts of the overlying conglomerate. They carry lenses of small pebbles and scattered pebbles. The pebbles are of quartz and granite, and as large as 2 inches in diameter. The matrix is very gritty, chiefly of quartz grains, but, unlike most of the conglomeratic matrix, it is not sheared, although faults have broken and displaced the dykes.

At the Apsey Lake locality, in addition to the dykes, there are fracture zones. The fracture zones seem to have been closed fissures, and it is thought that the dykes were open fissures which were filled from above, soon after their formation. The presence of these dykes seems to require a longer period of emergence than that required to cause the mud cracks which are so common in the formation. The dykes are thought to have been formed during a fairly long emergence, marking a decided change in conditions of sedimentation and suggesting a sharp break between the formations which are cut by these dykes and those overlying and younger than the dykes.

Thickness and Origin. The thickness of the member is put at 250 feet. The greywacke is thought to be wholly of shallow water origin, recording many short times of emergence which alternated with times of deposition.

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[1] Collins, W. H., op. cit., pp. 13 and 18.

Quartzite Member.

Stratigraphic Relations and Distribution. Above a thick transitional member the greywacke is succeeded by a well bedded, fairly clean, and for the most part fine-grained quartzite. The quartzite has numerous good exposures in two bands across Merritt township, and it covers most of the central part of Foster township. Easily accessible outcrops may be seen along the railway just east of Anderson lake and south of Merritt station. The quartzite shows on the shores of the north bay of Apsey lake, around Anderson lake, on the north shores of Loon lake, all around St. Leonard lake, on the southwest and on the east shores of Augusta lake, and on the southwestern shore of Elizabeth lake.

Character. In certain places there are dirty streaks which suggest a reversal to greywacke conditions; there are also some layers which show very arkosic materials, and grains as coarse as one-quarter inch in diameter. On the south shore of St. Leonard lake there are numerous exposures of highly feldspathic, fine-grained, saccaroidal quartzite which is finely lined upon weathered surfaces.

The lamination of the quartzite is its characteristic feature (Plate IV A). The lamination is of different types, and is made noticeable through different causes. It is due to variation in the materials deposited. The materials during deposition varied from fine-grained greywacke silt to clean quartz sand and to large pieces of feldspar one inch in diameter. The most abundant combinations producing lamination on weathered surfaces are quartz and greywacke, and quartz and feldspar. The greywacke is a dark green material, and the quartz is smoky grey, whereas the feldspar is pale pink, almost flesh colour. Ordinarily the alternation of greywacke and quartz is prominent on account of the difference in the colours of the materials, but the alternation of pale pink feldspar and quartz is not so noticeable. However, the feldspar is more soluble than the quartz, and weathers somewhat faster at the surface. The quartz remains solid and smooth at the surface, whereas the feldspar-rich layers are pitted. Most of the district has been burnt over, and the charcoal dust has gathered in the little cavities at the rough surface of the feldspar layers, giving a striking lined appearance to some of the otherwise not prominently contrasted feldspar and quartz layers. In other places, the pink porcelainic type of quartzite has lining of dark, translucent, blue grey quartz, and opaque pink feldspar, which lining is due to a real colour difference in the constituent minerals.

Similarly, in some places a massive, fine-grained feldspathic quartzite weathers to a patchy appearance, yielding smooth, porcelain-like, highly feldspathic areas, and blotches of grey, rough, quartz bearing surfaces. Some of the quartzite which is pale olive green on fresh sur-

faces, weathers in yellowish and reddish blotches. The red material is due to weathered iron oxide along bedding and fracture lines, and pale yellow is the colour of the kaolinite resulting from the weathering of feldspar fragments. This aluminous material is an insoluble residual weathering product, whereas the iron is more soluble and is leached from the quartzite and deposited in the bedding and fracture cracks.

In one place along the south shore of St. Leonard lake there is a thin (6 inches thick) layer of conglomerate in the quartzite. There are many small pebbles of quartz, granite, and pieces of mudstone in the arkosic rock. Another feature characteristic of some parts of the Serpent quartzite, is limonite-like spots on the surface of the quartzite. Examination shows that there is a considerable content of carbonate in the quartzite, which weathers to a characteristic tan colour. This type of quartzite is well exposed at Merritt station, and along the track west of the northwest shore of Loon lake. Near the top of the formation, there is pink weathering arkosic quartzite, interbedded with dark coloured quartzite and siliceous, slaty greywacke. It is the tan-flecked, feldspathic, saccaroidal, separate-grained (in contrast to the recemented quartzite) type of Serpent quartzite which is cut by a conglomerate dyke on the southwest shore of Augusta lake. There is another variety of this quartzite along the portage between lakes Elizabeth and Augusta, which is fine-grained and feldspathic in some layers, and sandy in other layers, and weathers to a very pale violet tint.

Under the microscope the Serpent quartzite is seen to be feldspathic, much more so in some places than in others. One chip taken from near the top of the formation is very coarse arkose. About 75 per cent of the thin section is feldspar, about 20 per cent quartz, and the rest carbonate. The arkose was originally loosely compacted and the carbonate fills original voids between the grains. The grains are rounded and large, rather uniform in size, composed of quartz, plagioclase, and microcline. Another thin section of similar arkose shows strained quartz grains, and broken feldspar grains. The grains average about 1 mm., although there are some of feldspar 4 mm. in diameter. In this section, as in many others, there are some areas of granulated quartz and feldspar filling spaces between the grains. Another section taken from pink, saccaroidal arkose shows a rather different type. The grains of feldspar and quartz are of irregular shapes and sizes. Some feldspars are weathered and others are unaltered, and some of the feldspars are clearly invaded by little veins of secondary quartz. In this specimen 60 per cent of the rock is feldspar.

Another type is more quartzitic, and contains at least 50 per cent quartz. Its feldspar grains are partly replaced by quartz. The quartz grains have made considerable secondary growth; they have suture

outlines, they invade feldspar grains, and they interlock like the quartz grains of the Mississagi quartzite. Unlike the other quartzite, however, there is a notable amount of carbonate in scattered rhombs and it is that which causes the tan spots on weathered rock faces.

Under microscopic examination the Serpent quartzite, or arkose, is not at all like the other quartzites of the region. It is notably rich in feldspar and characteristically marked by the occurrence of microcline. It contains carbonate crystallized among the quartz and feldspar grains. The clastic grains are commonly fairly well rounded, and not markedly weathered. Spaces between the large grains are filled with fine quartz and feldspar sand, and very little ferromagnesian clastic material. The arkose was probably loosely compacted; for there has been room for enlargement of quartz grains, not in all cases at the expense of the feldspar grains, and many feldspar grains have been sheared across and displaced, which could not have happened unless there was space to accommodate the movement of the offset parts. The arkose is almost free of sericite, and in general it is less metamorphosed than the Mississagi quartzite of the same area.

Thickness and Origin. In Merritt township the formation appears to be about 1,600 feet thick, but the overlying Gowganda formation, which is the next formation to be described, is on an erosion surface, and much of the formation was removed in that place. In Foster township the formation gives evidence of being possibly 8,000 feet thick, including a great upper member of pink arkose which is not found in Merritt township.

In general, the formation shows a gradation from very fine-grained clastic material to coarse, feldspathic ingredients. It is natural to suppose that it indicates an ancient shore-line contiguous to a continually rising land of considerable relief. The constituents of the arkose imply a close source of microcline feldspar, presumably a granite mass, poor in ferromagnesian material. The nearest granite now exposed is about 9 miles to the northwest and it contains no microcline, so far as known. However, it seems possible that orthoclase in weathering develops the typical microcline twinning,[1] and the writer concludes that the Serpent arkose was derived from the pre-Huronian pink gneissic granite described on page 22.

COBALT SERIES.

In the Espanola area the Cobalt series consists only of the Gowganda formation. It has three distinct members; the bottom of the formation is a basal conglomerate, at least in part, which grades into a well bedded slate, and that in turn gives place to a massive, slate conglomerate which looks like tillite.

[1] Barlow, A. E., Geol. Surv., Can., Ann. Rept., vol. X, pt. I, 1897, p. 198.

GOWGANDA FORMATION.

Stratigraphic Relations and Distribution.

Unconformably on the Serpent quartzite is a conglomerate formation which is thought to be the equivalent of the Cobalt conglomerate of Cobalt, and the slate conglomerate of Bruce Mines district. This formation is believed by several who have worked in the region to be of glacial origin.[1] In the Espanola area, this conglomerate appears in an east-west area 5 miles long, within one-quarter mile of the south boundary of Merritt township, and in another area 1¼ miles long and one-half mile wide, nearly in the middle of concession II, Foster township. The latter is near the middle of a southwesterly plunging syncline, which is cut off on the south and southwest sides by faults; the structure accounts for its isolated position and small extent. In this synclinal exposure 1,350 feet of the Cobalt series is exposed, consisting of 180 feet of irregularly bedded conglomerate and quartzitic layers, 450 feet of greywacke, part of which is well bedded slate, and 400 feet of massive boulder slate conglomerate, topped with fine-grained pink arkose which is exposed only for a thickness of 20 feet. Although the succession is cut out by faults, this pink arkose is thought to be near the top of the conglomeratic series and possibly the base of the overlying Lorrain quartzite,[2] which is found a few miles south of this area in La Cloche mountains.

Character.

The character of the formation varies from place to place, and this is especially true of the bottom part. It seems to be clearly unconformable everywhere in the district upon the Serpent quartzite, and from the difference in thickness of the Serpent quartzite remaining in Merritt township, and that remaining beneath the conglomerate in Foster township, there must have been an important erosional relief to the Serpent quartzite. It is unlikely that there could have been a very great difference in the thickness of original deposition of the quartzite within about 6 miles along the strike. In Merritt township, the conglomerate lies upon the lower part of the Serpent quartzite, which is almost white; whereas, in Foster township the underlying rock is pink arkose, a phase of the Serpent quartzite which is characteristic of its upper half, and especially of the top 1,000 feet.

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[1] Coleman, A. P., Am. Jour. Sc., vol. 23, 1907, pp. 189-192.
Bull. Geol. Soc. Am., vol. 19, 1908, pp. 347-366.
Jour. of Geol. vol. 14, 1908, pp. 149-158.
Collins, W. H., Geol. Surv., Can., Mem. 33, 1913, p. 58.
Wilson, Morley E., Geol. Surv., Can., Mem. 39, 1913, p. 97.
Jour. of Geol. vol. 21, 1913, p. 141.

[2] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8, 1914, p. 23.

Near the southwest corner of Merritt township, a slate conglomerate lies unconformably upon the quartzite. The quartzite is white, and vitreous in character, dipping 70 degrees south and striking north 81 degrees east. The line of contact runs north 105 degrees east. The base of the conglomerate is rubbly, beach-like in character, grading up into a massive greywacke matrix in which there are large boulders, as large as 2 feet in diameter, heterogeneously distributed throughout the mass. About 100 feet east of the last place mentioned there is no beach type of conglomerate to be seen; the greywacke boulder conglomerate, carrying a few pockets of quartzite, lies upon a surface of quartzite. One thousand feet still farther east there is another beach, or a continuation of the first beach, 100 feet above the base of the greywacke conglomerate. Then for 1,000 feet the contact of the quartzite and conglomerate is very well exposed. In most places the conglomerate is very pebbly and bouldery near the quartzite. Many large pieces of granite and quartzite lie upon the surface of the Serpent quartzite. The bottom 5 to 10 feet of very coarse conglomerate is overlain by about 50 feet of cobbles, grit, and pebbles which look like beach deposits. They lack marked lenticular forms and cross bedding lines, but they are metamorphosed, and such features may have been partly effaced. At the east end of this contact its bearing is north 125 degrees east, and at the west end north 80 degrees east.

This conglomerate grades into a slate member above it. The contact of the two is conformable and gradational. Mud was deposited while yet boulders and pebbles were occasionally being dropped in the same basin. For instance, in one place, one granite boulder 4 feet by 5 feet in diameter was found lying at the base of the slate formation with the slate bedding lines around it like flow lines. This slate is about 400 feet thick, Above it there is another conglomerate, 330 feet thick, which carries many quartzitic layers, pebbles, and boulders. There is next about 30 feet of slate, and above that is massive greywacke with a few scattered pebbles in it. It is not known how thick this last greywacke member is. Work in Mackinnon township would probably lead to much additional information in regard to the nature of this formation of slates and conglomerates.

Between lots 8 and 9, concession I, in Merritt township, the contact between Serpent quartzite and the slate conglomerate is visible. The quartzite strikes north 88 degrees east, but the contact runs north 79 degrees east. The contact appears to be a clean plane, with a boulder bed 8 feet thick on the surface of the quartzite. The boulders average 6 inches in diameter, they are well rounded, and for the most part of granite and schist; quartzite boulders are rare. They are so thickly set, that boulder rests against boulder in many cases, and the matrix is

coarse grit and pebbles. Above the deposit of boulders there is a dark coloured quartzite carrying many lenses of pebbles and boulders for 35 feet, above which it changes into that pebble-rich type of unbedded conglomerate with a sandy matrix, in which boulders are less common. In another part of the base, near the same locality, there is a pebble deposit at the contact with the quartzite, and boulders are abundant above the pebbles. Thus in general, the bottom of the conglomerate seems to be well bedded and irregularly stratified. The middle is predominantly massive, but the upper part of the member is well bedded, and grades by loss of boulders, pebbles, and finally large grains, into a clean slate. In this place the formation is much sheared, and the bedding is not everywhere distinguishable, but this part of the formation is not a heterogeneous mass. In its deposition water action has had a prominent part.

In Foster township, about 6 miles away, the group is similar in character, although it is different in detail (Figure 3). The west end of the outcrop shows the following succession: upon pink arkose the Gowganda group lies unconformably. The top of the pink arkose is apparently 8,000 feet above the base of the Serpent quartzite, of which it is a part. The base of the Gowganda group is a conglomerate of worn cobbles, and angular fragments of rock. It is a basal conglomerate only about 5 feet thick. It is followed by about 100 feet of conglomerate which is not at all like a beach deposit; there is no appearance of bedding, the boulders, cobbles, and pebbles are heterogeneously distributed both laterally and vertically throughout the matrix, and the matrix is a greywacke with little quartz grains scattered through it. The pebbles are of greywacke, schist, granite, and quartz. This conglomerate is succeeded by a group of pebble and quartzite layers, and partly stratified conglomerate, about 80 feet thick, which grades through siliceous greywacke, into a finely laminated, dark green, grit-free slate 450 feet thick. By being less well bedded and more siliceous, and, higher up, by the addition of little rock grits, pebbles, cobbles, and finally boulders, the slate gives place to a massive greywacke conglomerate much like the slate conglomerate near Bruce Mines. It carries many pink granite boulders; the matrix is dark green greywacke, yet there are so many red granite inclusions, that the whole rock looks red from a distance of a few hundred feet. The matrix weathers more readily than the granite, and the boulders stand out upon the weathered surfaces of the rock. In many places there are so many boulders in the rock, that an area of 100 square feet includes five boulders more than a foot in diameter. In most places there are not so many large boulders; 1 to 100 square feet is about the average distribution of boulders as large as one foot in diameter. The inclusions are of all sizes from finest sand to large

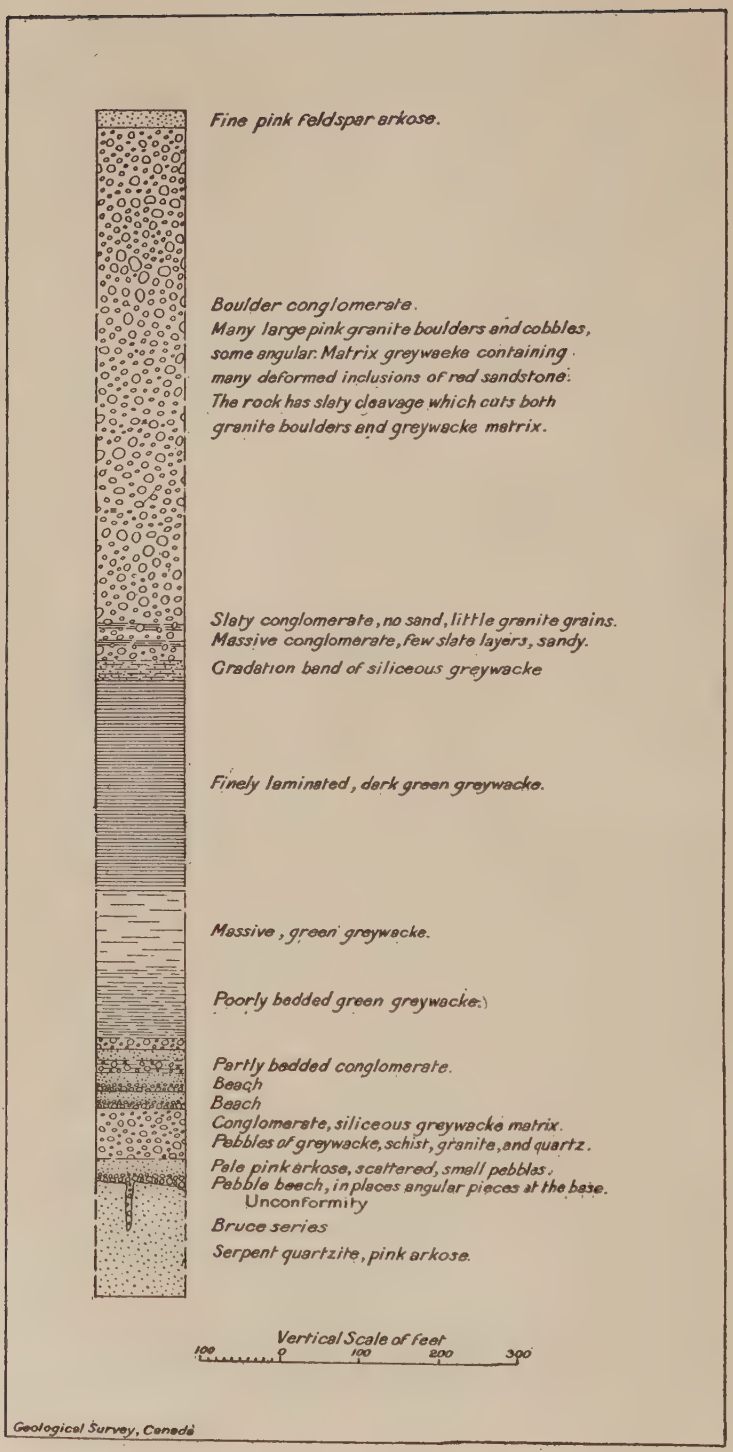
Fine pink feldspar arkose.
Boulder conglomerate.
Many large pink granite boulders and cobbles,
some angular. Matrix greywacke containing
many deformed inclusions of red sandstone.
The rock has slaty cleavage which cuts both
granite boulders and greywacke matrix.
Slaty conglomerate, no sand, little granite grains.
Massive conglomerate, few slate layers, sandy.
Gradation band of siliceous greywacke
Finely laminated, dark green greywacke.
Massive, green greywacke.
Poorly bedded green greywacke.
Partly bedded conglomerate.
Beach
Beach
Conglomerate, siliceous greywacke matrix.
Pebbles of greywacke, schist, granite, and quartz.
Pale pink arkose, scattered, small pebbles.
Pebble beach, in places angular pieces at the base.
Unconformity
Bruce series
Serpent quartzite, pink arkose.
Vertical Scale of feet
100 0 100 200 300
Geological Survey, Canada

Figure 3. Diagrammatic section of the Gowganda formation, Foster township.

boulders; one 4½ by 3 feet in diameter was seen. Apparently there were soft rock pieces as well as crystalline inclusions deposited in the conglomerate; for there are many distorted, scraggly inclusions of red sand, which appear to have been soft sandstone at the time of their deposition, and to have been deformed while or since the conglomerate was being deposited. These sandy inclusions are much like the pink Serpent arkose upon which the Gowganda formation is deposited, and it seems likely that the arkose was not indurated at the time of the deposition of the slate conglomerate, and that some of it was included together with granite boulders and other drift.

Slate Member. The slate member of the Gowganda formation evidently was deposited under water. In some places the lower 200 feet or so is not well stratified, but the upper part is very well stratified, and in some places all of it is. The slate grades up from the conglomerate conformably; it is plainly part of the same formation, and differs mainly in the lack of pebbles. It is notable for its very fine laminations, which are actually paper thin, in some places 50 to 60 to an inch, which show upon weathered surfaces as fine lining. The slate is a very fine-grained, argillaceous material, blue-green in colour.

Conglomerate Dykes. At this point we may revert to the conglomerate dykes mentioned on page 39. The composition of these dykes is very similar to that of the siliceous phase of the slate conglomerate, and, considering that they have been found in underlying formations, including the Espanola group, and the Serpent quartzite,[1] it is reasonable to conclude that they are formed by the Gowganda formation filling open cracks from above.

Microscopic Determinations. A thin section taken from the upper part of the slate conglomerate, where it looks much like tillite, shows that the matrix is argillaceous and chloritic. There are many very small chips of quartz and rock fragments. The grains are not rounded, they appear to be fragmentary, even though very minute.

The matrix of the conglomerate dykes is different from the slate conglomerate mentioned above. The matrix is decidedly siliceous, with fine argillite, largely chlorite, much brown biotite, and sericite in larger flakes. The inclusions are both rounded grains and angular chips. It is probably more like the microscopic appearance of the beach conglomerate at the base of the Gowganda formation than it is like the slate conglomerate at the top.

Thickness and Origin. In Foster township 1,350 feet of the Gowganda formation is exposed. The conglomerate of this region probably is the deposit of a glacier modified by the work of a body of water. The base

[1] Collins, W. H., Geol. Surv., Can., Mus. Bull. No. 8., pp. 12, 13, 18.

of the formation, in several places, seems to be a shore deposit. The upper conglomerate is much more like glacial till. The pebbles and boulders are mostly granite. Schist pebbles weather out leaving pits at the surface; whereas, the matrix is more soluble than the granite pebbles which stand out in relief on weathered surfaces. Rarely boulders are found larger than one foot in diameter. Smaller fragments are both rounded and angular. The matrix is dark blue-green in colour, composed of gritty rock flour. The conglomerate is not so much like metamorphosed boulder clay as is the slate conglomerate in the Bruce area. It is more gritty, and there is no laminated slate of still water deposition carrying boulders distributed through it as though dropped from floating ice; though the finely bedded slate formation strongly suggests the clays found in glacial lakes. The slate is in composition much like the matrix of the slate conglomerate at Bruce from which a striated pebble probably of glacial origin, was obtained.[1] Exception must be taken to the statement of H. E. Gregory,[2] "Polished, striated, and soled pebbles are not of diagnostic rank, and their absence does not imply the absence of glaciation." It is true that neither a polished, a striated, nor a soled pebble of itself is of diagnostic rank; yet, surely, polished, striated, and soled pebbles are of diagnostic rank, and their absence does imply the absence of glaciation, though it does not prove it.

The association of laminated slate with supposed tillite resembles the case of the Permian Squantum tillite described by Sayles,[3] in which laminated slate is a phase of the formation. The stratification lines are commonly interpreted as the result of annual changes of deposition. Near a glacier the amount of silt washed down is very great. It is possible that each layer may represent fluctuations between the flow caused by copious melting under bright sunshine, and the flow lessened by the nightly freezing. If diurnal change of temperature is really great, it might result in an appreciable fluctuation in the amount of water which escapes from the glacier, and affect the rate of deposition, and the size of material deposited. Such a possibility makes a great difference in the estimates of the times required for deposition of laminated clay and greywackes. The character of the slate suggests that it was deposited either in a lake or bay and that it was laid down in still water without either violent wave disturbance or tidal emergences. The character of this member in other areas has been described by both Collins[4] and Wilson.[5] Its argillaceous and even composition, and its position con-

[1] Collins, W. H., Mus. Bull. No. 8, 1914, p. 21.

[2] Gregory, H. E., Am. Jour. Sc. (4) 39, 1915, p. 304.

[3] Sayles, R. W., Bull. Mus. Comp. Zool., Harvard, vol. 56, No. 2, 1914, p. 166. Also Proc. Nat. Acad. Sc., vol. 2, 1916, p. 168.

[4] Collins, W. H., Geol. Surv., Can., Mem. 33, 1913, p. 49.
Mus. Bull. No. 8, 1914, p. 21.

[5] Wilson, M. E., Geol. Surv., Can., Mem. 39, 1913, p. 83.

formable above supposed tillite suggest that it may have been deposited in a post-Glacial lake, or in a land-locked bay. In Espanola area there were no striated stones found in the Gowganda formation, nor was any polished basement discovered which might point convincingly towards ice action. However, the massive conglomerate at the top of the formation in Foster township is like a glacial deposit, and from the nature of this formation elsewhere, it is concluded that the Gowganda formation at Espanola area is connected with a Pre-Cambrian ice-sheet, and that it was deposited at the borders of, but not generally beneath, a body of standing water.

KEWEENAWAN DIABASE.

Distribution.

Intruding all the other Pre-Cambrian rocks of the region is the series of basic injections usually referred to as the Keweenawan diabase.[1] In Espanola area, the diabase forms a more or less continuous band across the central part, roughly parallel to the general strike of the formations. There are numerous other masses of diabase irregularly distributed in the area, for the most part elongated masses with their long diameters parallel to the strike of the formations.

Character.

The physiographic features of the diabase masses have been discussed already under the general topic of the origin and development of cliffs and canyons. The diabase weathers by breaking off in massive pieces at cliff faces. On more level surfaces it assumes rounded forms due to the effects of glaciation, insolation, and solution. Just north of the railway bridge at Espanola Mills there is a good case of spheroidal weathering. The boulders stand in the disintegrated rubble of the parent rock, and from a distance look like boulders in glacial till. The entirely autoclastic character of the deposit shows that it is the result of weathering in place. Another noteworthy outcrop is a striated surface which has been uncovered by the railway cut about 2½ miles south of Espanola Mills. The diabase face is smooth, polished, and striated in sub-parallel lines. It looks somewhat like a glaciated surface, and strangely enough the scratches were made by pebbles in the adjacent conglomerate, but the rich development of chlorite, and evident slickensides, and the fact that the striations do not cut the fresh rock, but are made merely in the selvage, show that it is a plane of shear contact between the conglomerate and the diabase intrusion.

The diabase intrusions are either dykes or sills, and in some places they have the form of both; the beds are so nearly vertical that many layers of diabase injected along the bedding planes are vertical, so that they may be called either dykes or sills.

[1] Collins, W. H., Congrès Géologique International, 12ième Sess. Canada, 1913, p. 405.

Microscopic Determinations. Under the microscope the rock was found to be quartz diabase for the most part, but there is some gabbro. It is different in different dykes and even in different parts of the same injection. One variety is a diabase consisting of about 60 per cent phenocrysts of secondary hornblende, with some of the interstices filled with plagioclase and quartz. In this rock the quartz and plagioclase are not micropegmatitic. But quartz diabase is composed of oligoclase-albite laths stuck through a matrix of ferromagnesian minerals and micropegmatite. Dykes of gabbro, commonly called olivine diabase, occur with the diabase masses. In Nairn township a gabbro dyke intrudes a large diabase mass. Although the gabbro is mostly in small dykes, it forms a large mass one-quarter mile south of St. Leonard lake. There are also a few small dykes of gabbro porphyrite of which the groundmass is very fine-grained, and at contacts, glassy. Within it there are many phenocrysts of andesine-labradorite, but apparently no olivine. Therefore, there are injections of diabase, both quartz-free and quartz-bearing, gabbro, and gabbro porphyrite.

Quartz Diabase. Essential minerals and their approximate percentages are: oligoclase-albite, 40; quartz, 20; orthoclase, 15; and altered hornblende, 20. Accessory minerals are andesine, microcline, calcite, ferrite, zoisite, chlorite, and sericite or kaolin.

The texture is primarily diabasic. The plagioclase feldspar is in lath-shaped crystals separated by a matrix of micropegmatite and ferromagnesian minerals. The plagioclase has been very much altered, and absorbed by the micropegmatite. The orthoclase intergrown with the quartz is perfectly fresh, whereas, the plagioclase is much altered. This quartz diabase seems to be the result of a diabase having intruded siliceous sediments. Since the hornblendes and the plagioclase laths have been much altered, it is not clear why the orthoclase in the micropegmatite is unaltered if it were almost syngenetic with the plagioclase and hornblende. The high quartz content is likewise anomalous unless it is of secondary introduction. Contact metamorphism between diabase and siliceous sedimentary rocks seems to have resulted in this case in the introduction of potash and silica, forming quartz and micropegmatite with whatever potash was available, and partly absorbing the lime-soda feldspar crystals.

Other writers have concluded that much of the quartz and feldspar is micropegmatitic, is an original constituent of the rock, and is mostly near the middle of the dykes.[1]

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[1] Lawson, A. C., Am. Geol., vol. VII, 1891, p. 164.
Lane, A. C., Mich. Geol. Surv., vol. VI, pt. I, 1893-97, p. 238.
Bowen, N. L., Jour. Geol., vol. XVIII, 1910, p. 659.
Collins, W. H., Econ. Geol., vol. V, 1910, p. 545.
Hore, Reginald E., Econ. Geol., vol. VI, 1911, p. 55.
Hore, Reginald E., Jour. Geol., vol. XVIII, 1910, p. 272.

Diabase. Essential minerals are plagioclase feldspar, varying from andesine-labradorite to oligoclase-albite, in amounts varying from 25 to 65 per cent of the whole rock, and green secondary hornblende, varying from 70 to less than 20 per cent of the rock. Accessory minerals are magnetite, apatite, and biotite. Common secondary minerals are chlorite and quartz. The texture is ophitic and diabasic in some specimens, the hornblende is in hypidiomorphic crystals with feldspar in the spaces between them; and in others, feldspar laths penetrate the hornblende matrix. The texture is commonly granular, and marked diabasic texture is not common. The quartz is in small irregular grains with branchiate shapes invading both ferromagnęsian and feldspar minerals; it fills spaces between the other minerals, and has the vermicular form of micropegmatite.

Olivine Diabase. Essential minerals and their approximate percentages are: labradorite, 70; olivine, 15; and augite, less than 10. Accessory minerals are brown biotite, magnetite, and apatite. The texture is markedly diabasic. The plagioclase is in laths, with the spaces filled with augite; this, in turn, is penetrated by a large amount of olivine in hypidiomorphic grains. In the augite there are also grains of biotite and magnetite. In all other minerals apatite crystals are automorphic. The order of crystallization seems to have been, apatite, feldspar, olivine, biotite, and augite.

Gabbro Porphyrite. Essential minerals are phenocrysts of andesine-labradorite, other essential minerals are too fine-grained to be distinguishable. Secondary and accessory minerals are, calcite, titanite, pyrrhotite (?), pyrite, chlorite, sericite, magnetite, hematite, few small saussuritized plagioclase phenocrysts, and propylitic ferromagnesian minerals. The groundmass is almost black in colour, very fine-grained, and of felty texture.

Contact Metamorphism.

Absorption. The physical effects of the intrusions upon the sedimentary rocks are not great, but the chemical alteration is marked. The dark-mineral radicals of the basic dykes and sills have penetrated the quartzite for a considerable distance from the apparent true plane of contact. The manner of this penetration seems to be shown by numerous instances of partly or wholly absorbed quartzite inclusions in the dykes of the district. Instances of this are to be found 1½ miles northeast from Thessalon station, where a diabase dyke is so closely set with quartzite inclusions as to be an agglomerate. The quartzite fragments are deangulated and assimilated to such an extent that they have hour-glass and other re-entrant curved forms. Fourteen chains south of mile-post 55 on the Canadian Pacific railway, just west of Blind River town, the diabase shows numerous inclusions of quartzite. The

quartzite gives evidence of partial solution by its rounded outlines, and by a sort of "ghost" outline to which the quartzite originally extended, but which lies now in the diabase. Other quartzite masses seem to be spotted through with a few crystals of hornblende, possibly the recombination of impurities of the original quartzite, but since gradation into much darker borders around the edges is very common, it looks much more as if the ferromagnesian radicals had penetrated the quartzite by chemical diffusion. Furthermore, there are some places where the hornblende crystals are very large, a few inches in length, and scattered throughout the quartzite to such an extent that the sedimentary rock looks like a diabasic igneous rock. A striking example of this is to be seen in the neighbourhood of Long Lake mine, a few miles south of Naughton. In some places the quartzite has been so altered by the basic intrusion, that under the microscope there is no sign of its original clastic character, although it retains traces of the quartzitic bedding lines and the fracture common to most of the quartzite of the district.

It is scarcely to be expected that so basic a rock as the diabase could be intruded into almost pure silica without a considerable amount of fluxing taking place; but the question is, how great is the extent of this action? Although not nearly enough investigation has been done to answer this question, field observation suggests that the influence of the quartzite and the diabase on one another nowhere extends more than 12 to 15 feet. Nevertheless, in such places where the dyke is glass next to the intruded wall rock, contact metamorphism is merely a physical change, mylonization of the intruded rock along the plane of contact, with no apparent chemical alteration.

Microscopic Determinations. In order to test the question of a molecular diffusion at contacts, several collections of rock chips were made across contacts of diabase and quartzite, and of diabase and greywacke formations in Espanola area; these specimens have been studied under the microscope.

A series of specimens taken across the contact of diabase and arkosic quartzite seems to show penetration of the diabase by quartz, and migration of basic radicals from the diabase into quartzite. Within the diabase the feldspars and metasilicates are partly replaced by irregular segregations of quartz. Quartz is in branchiate, vermicular forms, and in irregular grains of botryoidal shapes, invading both feldspars and hornblende crystals. In some cases, included quartz is not entirely absorbed and forms glomero-phenocrysts with plain margins between individual grains but with very irregular exterior borders. In other cases quartz is in the form of micropegmatite. The micropegmatite fills spaces between the diabase minerals, and even seems to have absorbed parts of them.

In a thin section collected near a contact of greywacke and diabase, the diabase consists chiefly of oligoclase-albite phenocrysts ($Ab_{95}An_5$) in a micropegmatitic matrix. The plagioclase laths are partly resorbed by the pegmatite. The phenocrysts are saussuritized, but the pegmatite of quartz and orthoclase is not altered. If this is a contact metamorphic effect, lime-soda feldspar has been replaced by silica and potash feldspar, and the micropegmatite is of epigenetic origin. It is possible that the saussuritization is a change of long standing, preceding the crystallization of the micropegmatite, and that it took place before the complete solidification of the diabase; if so, the micropegmatite is probably syngenetic; however, the presence of quartz in irregularly shaped grains points to the introduction of some quartz, and it is thought that the micropegmatite also is epigenetic.

Another section of quartz diabase, taken from near the contact of an intrusion into siliceous quartzite and granite, shows automorphic crystals of little altered oligoclase in a granular matrix of quartz-orthoclase pegmatite, and some much altered ferromagnesian mineral (probably originally augite, now hornblende, chlorite, sericite, calcite, and epidote). The micropegmatite appears to be in granular units, within which the arborescent stringers of interwoven quartz and feldspar are very minute. Each unit seems to have the form of a feldspar crystal in spite of its quartz-orthoclase composition, and each grain, in regard to both quartz and feldspar, is an individual crystal, apparently unconnected crystallographically with the quartz or the orthoclase in adjoining grains. E. S. Bastin[1] has described a similar case of micropegmatite in the pegmatites of Maine. He describes the feldspar crystals as feldspar "brushes." There is no doubt that micropegmatite forms in the interstices of granular rock as the last, eutectic crystallization of the quartz diorites of the region. Collins[2] has described this type of micropegmatite in rocks of Nipissing district, and recently N. L. Bowen[3] has discussed fully the chemistry of such a process. Nevertheless, in the case here described some of the micropegmatite seems to be an effect of contact metamorphism; for the thin section shows not only micropegmatitic texture, but also cataclastic materials, all of which are quartz and feldspar fragments, some of which appear to have been reorganized into a micropegmatitic intergrowth, although none of the pieces is a fragment of micropegmatite. The development of micropegmatite appears to be younger than the cataclastic material, and it is thought to have been formed by interaction of the acidic rocks with the basic intrusion soon after injection took place.

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[1] Bastin, E. S., United States Geol. Surv., Bull. 445, 1911, p. 23.
[2] Collins, W. H., Econ. Geol., vol. V, 1910, pp. 541-42.
[3] Bowen, N. L., Jour. of Geol., vol. XXIII, 1915, Supplement, p. 40.

In addition to those large crystals of hornblende which are in quartzite near contact with diabase, under the microscope it is seen that there are many small crystals of pyrabole which separate and surround many of the quartz grains, and the quartz grains are speckled with small pyrabole fragments or crystolites. In the quartzite there are some segregations of pyrabole, and these segregations carry quartz phenocrysts which seem to be the fusion or crystallization into one crystal of many small fragments. Along the borders of these pieces, pyrabole fragments remain behind, although in many cases the line of separation between quartz fragments is obliterated. Thus it happens that small pieces of hornblende and sericite (?) are stranded within a quartz crystal. Around the borders of the quartz small pieces are oriented not quite parallel to the main crystal's growth, and it is supposed that they are brought gradually into alignment by crystallizing forces. In more clastic specimens, some quartz grains show enlargement by crystal growth, but the parent grain is full of inclusions, whereas the added border is clean quartz. Possibly some of the ferromagnesian minerals within the quartzite are the reorganized impurities of the quartzite, but there is no doubt that there has been a considerable transference of diabase minerals into quartzite near the plane of contact.

At the contact between diabase and greywacke, and even within the greywacke near the contact, there are segregations both of siliceous and of basic minerals. Hornblende seems to be in very small, unoriented fragments in the basic parts, and acid radicals form small, quartz-orthoclase glomero-phenocrysts of granular micropegmatite. In the micropegmatite there are distinct, interlocking granules of quartz and orthoclase. Many of these glomero-phenocrysts of micropegmatite are clearly secondary, for bedding lines of inclusions run through them. Micropegmatite in the diabase, even when replacing plagioclase feldspars, can be explained as possibly primary, but it seems necessary to grant that micropegmatite in the sedimentary rocks is epigenetic. If it is epigenetic in one rock near the contact, presumably some of it in both is not an eutectic crystallization but an absorbent, contact metamorphic effect between the quartzitic sedimentary rocks and the basic intrusions.

W. S. Bailey[1] reported that the quartzite at Pigeon point, Minnesota, is intruded by gabbro, and altered at the contact into a red, feldspathic rock (commonly referred to as the "red rock"). Quartzite inclusions in the gabbro have borders of the same kind of material; evidently it is a contact metamorphic effect. Within this red rock there are irregular and club shaped masses of quartz, and micropegmatite. The writer is indebted to Professor F. F. Grout, of the university of Minnesota, for the opportunity of examining several thin sections of the rocks at Pigeon

[1] Bailey, W. S., United States Geol. Surv., Bull. 109, 1893, pp. 101-102.

point. In the red rock, collected at the contact of quartzite and gabbro, there is granular micropegmatite like that described by the writer, each feldspar grain controlling the quartz within it. In the gabbro, quartz is included or absorbed in the form of irregular grains, and in vermicular and branchiate masses filling interstices between feldspars. Within the quartzite there is the reorganization of little quartz and feldspar grains into primitive micropegmatite. Thin sections made from specimens collected by Professor Grout from the contact of gabbro and lake Superior sandstone at Duluth show similar things. Within the sandstone there are granular segregations or replacements of micropegmatite, and in the gabbro there are quartzitic replacements about the feldspars. Therefore, it appears that micropegmatite is not only an end product of crystallization in quartz-diabases, but that it is a phase of absorption in contact metamorphism.

Quaternary.

GLACIAL.

Pleistocene formations are scanty in the Espanola area, but there are some glacial deposits in the northern part. On the north side of the wagon bridge at Espanola Mills, there is a deposit of glacial boulder clay at the edge of the lake beds, which lie against and upon part of the glacial deposit. A few chains northeast of the corner between the trunk road and the road to Espanola station, there is a gravel pit, in what looks like glacial outwash, overlain by a few feet of clay.

POST-GLACIAL.

Lake Sands.

The glacial deposits proper are not abundant, but deposits in the lake which followed the ice invasion are widespread. The greater part of the northern half of the area is covered by a water-laid sand. At Espanola Mills there is at least 60 feet of sand above bedrock,[1] and in the young valley of the Spanish river, a mile southwest from Espanola Mills, there is a 60-foot exposure of sand. The sand-plain seems to be the result of a valley having been filled with lake deposits, for the hills rise from the flat surface abruptly, without the usual basal slopes. Judging from the sand exposures just mentioned, the bottom of the valley must be several scores of feet below the present surface, and it may be much lower in some places. About one-fourth of a mile south of the wagon bridge across Spanish river, there are several large dunes on the sandy plain. Although now covered with grass and the stumps of spruce trees, the dunes retain their crescentic form, concave towards

[1] For this information the writer is indebted to the courtesy of the manager of the Spanish River Pulp and Paper mills. These data were determined during boring operations in connexion with the building of the plant.

the southwest. A few chains west along the road from the north end of the wagon bridge, one may see the shore deposits of the old lake. They lie at a higher level than the glacial till near the same locality, and partly upon it. Probably, these deposits of sand were laid down in Pleistocene times before the ice-sheet had retreated far enough to allow the pent up waters to escape. They may have been deposited during the Algonquin-Iroquois stage.[1]

Stratified Clays.

On the north side of Spanish river, between the two bridges, there is a thick band of stratified clay (Plate IV B). It is notable in that it carries many strange inclusions resembling concretions. It is interlaminated clay and sand like the siliceous, Huronian members, and carries numerous pebbles and boulders in its well-bedded matrix. Many of these are glacial, and are confined to the lowest 10 feet of the deposit. A similar case has been reported by Collins,[2] who states that the Saugeen beds near lake Timiskaming are stratified clays which carry well-rounded large pebbles in a well laminated matrix. Collins calls attention to the striking similarity between these deposits and some of the boulder-bearing laminated slates of the Cobalt series. In the Espanola locality the section exposed is 54 feet thick, and in the lower part there are numerous ripple-marks, many of which are overturned in contemporaneous drag folds. One layer was seen which showed these little drag folds overturned in opposite directions towards the middle at each side of the deposit.

The clay lies between two hills, which are thought to have afforded the conditions of shelter necessary for the deposition of the fine material composing most of the deposits. Some of the boulders are thought to have been floated in by ice, and others to have rolled down the steep hillsides out on to the frozen surface in winter, and to have dropped through to the bottom in the spring.

Marlekor or Imatra Stones.

Attached to some of these rocks in the bedded clays there are smooth argillaceous masses. There are also concretion-like masses of clay which are not connected with rocks or any other apparent attachment. They are not concretions in the sense that a ferruginous concretion is the chemical concentration of a cementing material, which, in most cases by its dehydration, forms a hardened unit. They seem rather to be the indurated remains of a viscous fluid which was covered by fine materials. It is well known that clay and water may be mixed in all

[1] Frank Leverett and F. B. Taylor, U.S. Geol. Surv., Mon. 53, 1915, p. 453.
[2] Collins, W. H., Geol. Surv., Can., Mem. 33, 1913, p. 56.

proportions, and in the ceramic industry such a fluid mixture is called slip. In plastic clays much of the water is in combination with the aluminum oxide and silica, forming kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and higher hydrates; such clays may be air-dried to hard and strong casts, and it is done continually in pottery manufacture. Now, the form of the inclusions suggests that they were formed from the localization of viscous clay slip which was buried first in the silts, and later indurated by the loss of associated and loosely combined water. Some of these inclusions show plainly that they were rolled in the water while they were still very plastic. Others show that they were not moved after they first accumulated, and they bear upon their surfaces peculiar, irregular, little ridges of unknown origin. These inclusions owe their cementation partly to the presence of calcium carbonate; but they owe their forms to the fluidity of the clay slip from which they seem to have hardened. Such inclusions are known as marlekor (singular marleka) or imatra stones.[1]

Erdmann[2] described similar "concretions" from the glacial clays of Sweden, and mentions that Kjerulf supposed that such marlekor were rounded by the agency of water, and then buried in the mud. But Erdmann, himself, does not follow Kjerulf in this belief, nor does he agree with Sars that they are formed around the remains of shells and fishes; Erdmann had not found any such organic nuclei as those which Sars had reported from Norwegian localities. However, Liesegang[3] quotes Richters[4] as authority for the report that in each centre of a double marleka there was a very well preserved snail shell; the shell was not altered, and the cementation of the concretion had come about by the addition of calcium carbonate from without. This is the means of formation favoured by Erdmann, although he does not lay stress upon the necessity of a nucleus. Liesegang[5] thinks the marlekor are chemical phenomena, but he fears there is no probability of their being explained. By him they are not thought to be concretions due to chemical diffusion, because most of them lack the nuclear centre requisite for such formations. Wilson[6] has described similar phenomena from the Kewagama Lake area in Quebec. He thinks that they were formed in place by the solution and redepositing action of fluctuating ground water, and that they are true concretions of lime carbonate with a certain amount of included foreign matter. Erdmann cited cases of marlekor which carry 40 to

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[1] Parrot, G. F., Mem. de l'Acad. Imp. des Sciences de St-Petersbourg 1849, and "Recherches physiques sur les pierres d'Imatra," 1840.

[2] Erdmann, A., Exposé des formations quaternaires de la Suède, Stockholm, 1868, pp. 84-87.

[3] Liesegang, R. F., Geologische Diffusionen, Dresden and Leipzig, 1913, p. 159.

[4] Richters, F., Ueber Marlekor, Prometheus 23. 697 (1912).

[5] Liesegang, R. F., op. cit., p. 158.

[6] Wilson, M. E., Geol. Surv., Can., 1913, Mem. 39, p. 105, and Plate XXVII.

66 per cent calcium carbonate in a matrix which contained only 0·5 to 3 per cent of this substance, but the inclusions at Espanola are not nearly so calcareous.

It seems evident to the writer that not all such inclusions are chemical concretions, and he follows Kjerulf in believing that many of them were formed, and rolled about by water action, while they were still in a plastic condition, and before they were covered by the mud and silt which formed their present matrix. Plate V shows the flow lines in the marlekor. These cases do not prove that no marlekor are true concretions formed by the segregation of lime from the surrounding clay; but it is thought that these particular specimens are the dehydrated and cemented products of viscous clay slip.

CHAPTER V.

STRUCTURE.

GENERAL STRUCTURAL CONDITIONS.

The Bruce series consists of about 1,000 feet of greywackes, conglomerates, and thin limestones, underlain by about 4,000 feet of quartzite, and overlain by possibly 8,000 feet of quartzite. In some places several thousand feet of the upper quartzite was eroded before the deposition of the overlying Cobalt series. The Cobalt series consists of about 1,000 feet of conglomerates and slates, overlain by several thousand feet of quartzite. This Cobalt quartzite, called the Lorrain quartzite, is not known to be in Espanola area, but its great thickness a few miles to the south in La Cloche mountains leads to the supposition that it was originally deposited over the Espanola area. These Huronian rocks rest upon an ancient basement of schists and greenstones, and they strike from north 40 degrees east, in most places, to north 90 degrees east in the central part of the area; the dips are high, differing from 50 degrees south to vertical. With outcrops about parallel to the strike of the rocks, three major faults and several minor faults break up the terrane into steeply tilted slices. Although the incompetent limestones and greywackes show intense drag folding, the strong quartzite members are little warped, and they have controlled the major structure of the region. However, in the south-central part of Foster township there is a southwesterly plunging syncline within which lies an outlier of the Gowganda formation, and there is still more folding farther south (see page 67).

The pre-Huronian sediments are greatly metamorphosed, but their exposures are not large enough in this area to give much idea of their structure; however, their strikes are mostly east and west, and their dips are about vertical. Their present deformation seems to have been almost completed before the period of diastrophism which caused the structure of the overlying Huronian rocks.

SUMMARY OF EVENTS.

The Bruce and Cobalt series form a competent terrane which it is thought was first slightly warped by a growing thrust from the south, and as this force gradually grew the essentially rigid quartzite members broke. The nature of this first yielding to pressure is that of the so-called break thrust.[1] This break, at the characteristic

[1] Willis, Bailey, U.S. Geol. Surv., 13th Ann. Rept., 1891-92, p. 223.

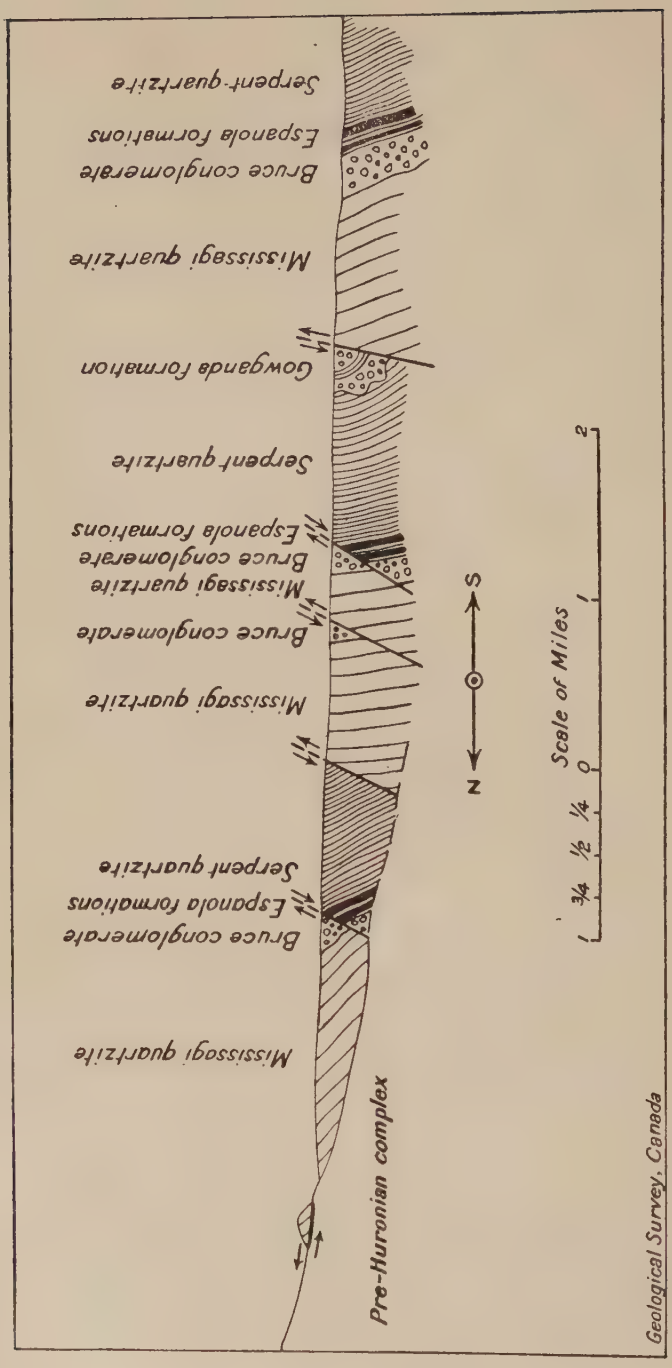


Figure 4. Generalized cross section of Espanola area.

angle of fracture (presumably about 40 degrees), was probably of great displacement, and relieved the strain for that time, but later stresses accumulated until the member broke again. A third great break seems to have brought the Mississagi quartzite, at the base of the Bruce series, into contact with the top of the Gowganda formation. At that stage the strength of the member would be so increased, due both to shortening and to thickening, that movement along the bedding planes will be effected more easily than shear across the formations. The accumulated stress appears to have been so great that the terrane finally closed up like an outspread pack of cards, and rode over the underlying metamorphosed basement along a low-angled fault plane. This movement accompanied a general steepening of the dips of the bedding, and thereby caused very great intraformational shearing.

FIELD DATA.

Overthrust Faults.

It is believed that the quartzite ridge which stretches from the high hill just south of Espanola station, on the Canadian Pacific railway, to the north boundary of the area, near the line between Baldwin and Nairn townships, and farther to an unknown distance, is thrust over upon the pre-Huronian sediments as an outlier. There are several reasons for this belief. On the south side of the quartzite ridge, 20 chains west from the Algoma Eastern railway, along the trunk road, about one-quarter mile north-northeast of Espanola Mills, there is a fault plane, apparently dipping northward at a low angle, beneath the younger quartzite and above the greatly metamorphosed pre-Huronian sediments. The pre-Huronian quartzites and slates outcrop on the lower land to the southwest of this high quartzite ridge. Again, 30 chains north of this fault, on the other side of the high hill, there are pre-Huronian schists. Then in concession I, Baldwin township, on the line between lots 2 and 3, there is a fault between the younger quartzite and the pre-Huronian schists and greenstones, and the fault plane appears to dip at a low angle towards the south; this fault outcrop is on the north side of the ridge. Thus there is a high ridge of quartzite (Mississagi quartzite, described on page 25), bounded on the north, west, and southwest sides by pre-Huronian rocks; the bedding of the quartzite seems to be in a vertical position, whereas the bedding of the underlying rocks is indeterminable; and actual fault contacts have been found on both the south and north sides of the quartzite ridge. For these reasons the quartzite ridge is interpreted as an outlier of the Bruce series, which has been thrust over upon the pre-Huronian rocks in a great overthrust terrane having a width along the fault plane of over 20 miles.

Minor Faults.

A normal fault between the Bruce conglomerate and the overlying limestones and greywacke formations is not hard to trace because of the marked lithological differences of the rocks involved. Its stratigraphic throw is nowhere more than 400 feet, if the younger formations faulted against the conglomerate have been correlated correctly. Near the line between concessions III and IV, west of Griffin and Apsey lakes, the fault appears to have branched into several members, and to have been cut by another fault with a northwesterly bearing. Near Merritt station, showing along the railway and on the southwest shore of Loon lake, another normal fault, which was traced for 3 miles, forks into at least two branches. It lies south of the two thrust faults which cause repetition of the Huronian formations, and which are described in the following section.

In the northeast part of Foster township the Bruce conglomerate has been offset almost a mile by a fault at right angles to the general strike of the rocks. This fault may be a thrust fault in almost vertical position, caused by the difference in horizontal displacement of different parts of the terrane involved in the great overthrust fault. It is plain that the terrane has been displaced in the neighbourhood of Brazil lake 2 miles farther north than it has been displaced either east of lake Augusta or west of Merritt township. This can be seen easily if a line is drawn across the accompanying map from the base of the most northerly outcrop of Bruce conglomerate, near the west boundary of Merritt township, to the corresponding outcrop at the northeast end of lake Augusta. The Bruce conglomerate lying between these two points is from 1 to 2 miles north of the line joining the points, and at each end of the line there are notable faults offsetting the central terrane towards the north. These transverse faults and the two normal faults are interpreted as relatively superficial phenomena, incidental to the major thrust faults now to be described.

Thrust Faults.

In addition to the overthrust fault, there are three thrust faults of great throw, whose original angles of rupture are unknown. Although the fault outcrops are hard to trace, the faults have caused repetitions of the Huronian series which are plain. The most northern fault seems to lie in a direction almost due east and west, nearly parallel to the strike of the highly tilted quartzites. It is hard to find, because it is between steeply dipping quartzites, much sheared parallel to the bedding, and very similar lithologically. The fault breccia has been seen on the east shore of Apsey lake, due east of the little island south of the narrows, and on the south side of a diabase ridge $1\frac{1}{4}$ miles west of the same island;

a fault in lot 8 on the south boundary of Hallam township is thought to be the continuation of the same fault. It is supposed that the fault passes between the quartzite hills in Hallam township, and that it lies beneath the sand-plain. A mile east of the outcrop of conglomerate on Apsey lake there is a little lake, near the south shore of which there is the continuation of the same fault. From there eastward it has not been traced. It is thought that it passes to the north of the large point on the west shore of Loon lake, and it appears in lot 5, concession IV, Foster township. A fault zone continues northeastward from that place passing between lakes Augusta and Panache, and crossing the eastern boundary of Foster township. By this means Bruce conglomerate and the Espanola formations are brought close to Gowganda conglomerate on the north side, and to Mississagi quartzite faulted against them on the south side.

There is another fault less well exposed. A small outcrop of conglomerate on the southwest shore of Apsey lake drew attention to a fault between the quartzite and the conglomerate north of it. (See also pages 29 and 30.) The quartzite is so nearly vertical in position and so much sheared, that the fault would not have been discovered if the conglomerate had not been there. Westward the conglomerate is cut out within 200 feet of the lake, and the fault line could not be traced farther. But on the south side of a quartzite hill one-half mile west of the eastern boundary of Hallam township, and a little to the east of the boundary, there are other fault outcrops, almost surely part of the same thrust fault. Westward it probably intersects the other thrust fault just described. Eastward from Apsey lake the fault is supposed to pass across a swamp on the east side of the south bay. It could not be found in any of the rock outcrops around the swamp. What is taken to be a continuation of the same fault is on the south shore of the larger point on the west side of Loon lake, and it appears to continue eastward to where it is cut off by the third great fault now to be described.

Cutting off the fault just described, in the southeast corner of Foster township, there is a fault of very great throw. The fault outcrop runs from the southern boundary of Foster township, nearly on the line between lots 9 and 10, in a northeasterly direction into the most westerly bay of lake Panache. This fault has brought the lower part of the Mississagi quartzite into contact with the top of the Gowganda formation.

Although the outcrop of none of these great faults has been traced continuously across the area, the distribution of the rock formations requires their presence. In the structure sections on the map which accompanies this report, the sequence and repetition of the formations and the faults are shown diagrammatically. It is difficult to correlate and to distinguish formations so similar as the Mississagi and the Serpent quart-

zites, and the Bruce and the Gowganda conglomerates, so there may be errors in the interpretations; however, thanks to a persistent application of the criteria mentioned in the descriptions of the various formations, it is confidently believed that every outcrop of more than 4 square chains area has been identified correctly. In any case the fault outcrops discovered and the repetitions of the Huronian series are the evidences of the major thrust faults discussed.

MECHANICS OF THE POSTULATED MOVEMENTS.

Structural deformations depend largely on three factors: the character of the stresses, the physical nature of the terranes involved, and the shape of the members deformed.

Character of the Stresses.

All stresses may be resolved into the two classes, shearing stress and compressive stress including its negative phase, tension. In most cases it is not possible to resolve earth forces into their true components, because of lack of data; therefore, most American geologists classify the deformations. All deformations are either translational or rotational strains.[1] Nevertheless, within the same member, plain translational stresses have given rise to folding or buckling strains, shearing strains, and local ruptures, both translational and rotational strains.

Physical Nature of the Members Involved.

Geological terranes may be rigid, plastic, or both combined, viz., plastico-rigid bodies. For many years the mechanics of rigid bodies have been known, for structural mechanics is an old science and engineers have investigated the behaviour of rigid bodies under stress. But plastic bodies are in quite a different class, and their behaviour under stress is markedly different from that of rigid bodies. In general, the strained rigid body ruptures at its limit of elasticity; the plastic body has no definite limit to its deformability; typically it does not rupture, it flows. Between these two classes there is perfect transition.

Series of rock formations are characteristically heterogeneous; they are composed of both plastic and rigid rock, of readily folded layers, and of massive, unyielding members. But in spite of their heterogeneity, terranes which have been deformed show, by the nature of their deformation, whether they were in fact rigid, or plastic, or a combination of both. For example, a clay formation may contain many disseminated, rigid quartz grains, but the formation as a whole is plastic. Vice versa,

[1] Leith, C. K., "Structural geology," 1913, p. 16.

the same clay formation may be enclosed above and below by thick, rigid quartzite members, and the whole terrane may be one of great competence. Thus, many terranes which contain very plastic layers are rigid entities, and mixed members are either rigid or plastic bodies according to the distribution and proportion of their constituents. In general, rocks are peculiar in being relatively weak in resisting tension, but they are strong under compression.

Shape of the Members.

Compression, as we consider it for unsupported, homogeneous, rigid bodies, is relieved in many ways which depend on the shape of the members deformed. This seems to be a consideration neglected by geologists, probably because the original shape of the deformed members is generally indeterminable. Willis[1] has pointed out the importance of the original attitude of the formations deformed, and the influence of initial dips. In many cases the attitude of the formation results from thrust forces which have deformed the formations. Going back to the cause of that particular attitude, in a general case we must consider the original shape as well as the original dips of the formation affected.

Among engineers it is a matter of common knowledge that the effect of thrust is different upon short blocks, long columns, plates, and irregular masses. It is also recognized that the shape of the end of a column influences the nature of its flexure and its breaking strength. The shape of the end of the member determines where the member will start to bend under thrust. It is well known that a long column is more flexible than a short one. It is easy to bend a long steel rod, but it is hard to bend even a thin one if it is short. The effect of flat ends (also known as flat bases, square ends, and fixed ends) on a column is to shorten that part of the column which bends (Figure 5a); with round ends, the column bends from end to end, having the greatest flexibility of all columns of equal dimensions (Figure 5b). If a column has round ends which are clamped before flexure in such a way that the column cannot turn about its axis, nor yield in any way at its ends, its strength becomes that of a column with fixed ends, because the whole length of the column does not take part in the bending. Any fixed end, whatever its shape, gives a rigidity to the member greater than that given by a round, revolving end. The strength of a column with one square or fixed end and one round end lies between that of the two types (Figure 5c). A column with two fixed ends is four times as strong as a similar column with round ends, and nearly twice as strong as a column with one fixed end, and one end rounded but so held that it can yield only in one direction (technically known as a pin-and-square end).

[1] Willis, Bailey, U.S. Geol. Surv., 13th Ann. Rept., pt. 2, 1891-92, p. 249.

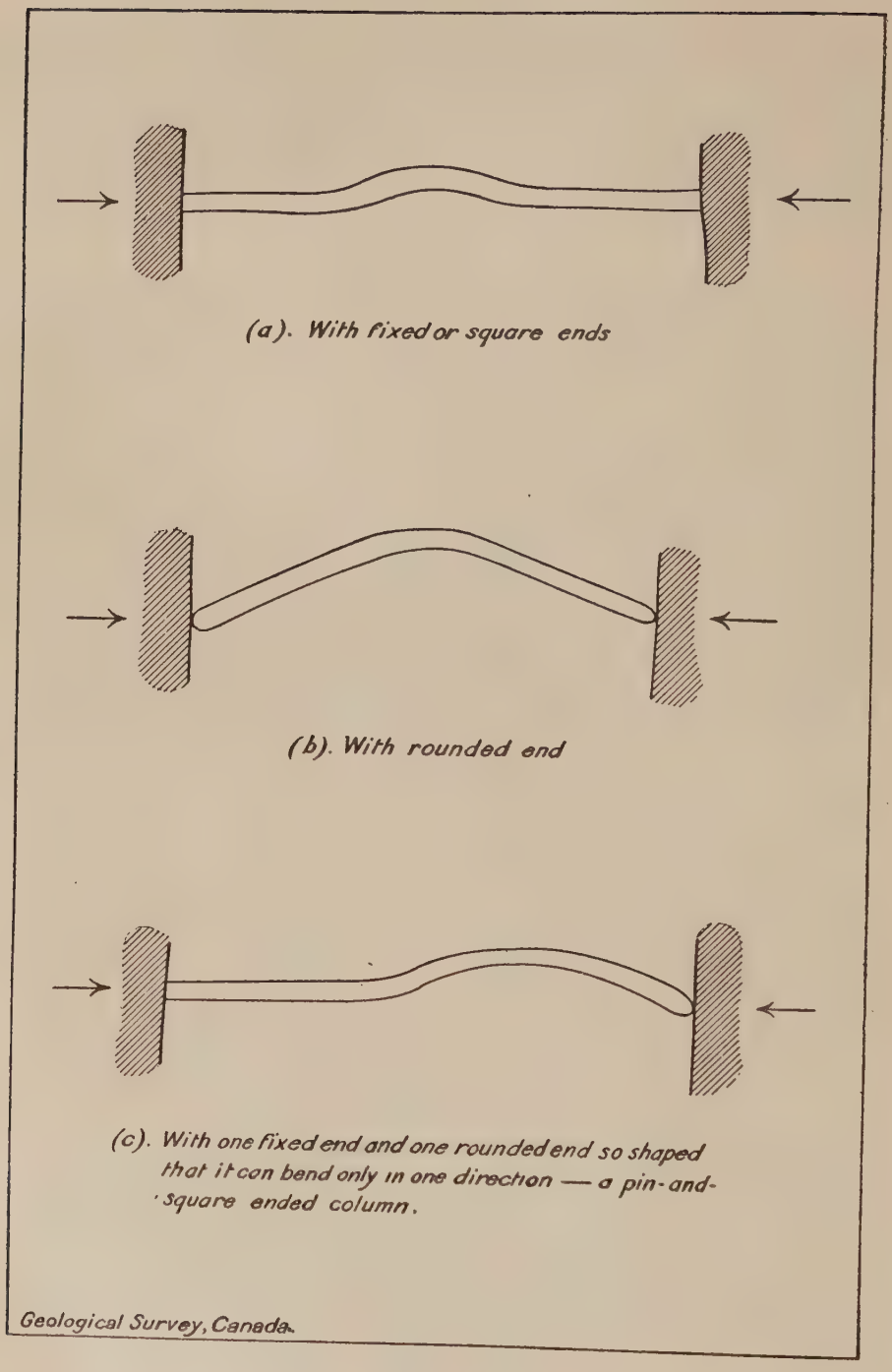

(a). With fixed or square ends
(b). With rounded end
(c). With one fixed end and one rounded end so shaped that it can bend only in one direction — a pin-and-square ended column.
Geological Survey, Canada.

Figure 5. Flexure of column.

Nearly all geological experimentation has been done on square ended sheets, and on short, square ended columns. It is probable that masses of the earth's crust which have been deformed were, for the most part, originally of wedge or lenticular shape; in some cases the ends of the members are held in such an incompetent matrix that the effect is that of a round end, and in other cases they are held by such a rigid massif that the end is a firmly held abutment like a square or fixed end. Such conditions influence the place of the bending, and the flexure controls the position of the breaks, if such occur.

It would be wrong to regard a flat-lying terrane under compression as a compilation of many cubic blocks placed one against the other, and to regard the strength of the whole as that of any one of the parts, for in this way the strength would be overestimated greatly.[1] Although such an analysis would be right in the consideration of a single one of those blocks, it would be misleading for a prediction of the behaviour of the composite whole. The terrane is not a block but a sheet, and it follows the mechanical behaviour of a thick sheet. If a sheet varies in thickness from one end to the other, its deformation under thrust is different from that of a plate of uniform thickness. A device commonly used in the arts is a thickening of the central part of a member in order to prevent flexure. A familiar example is the thickening of the central part of the pitman rod in many steam engines. Of course a pitman rod is a column, but the mechanics of a plate under compression are closely analogous to those of a column,[2] and a plate with a thick centre is a rigid one. Thus, a lens-shaped terrane of rigid rock is a very strong member.

Applications to the Espanola Structure.

The Huronian rocks at Espanola are a rigid part of a lens-shaped, heterogeneous, plastico-rigid terrane which has been deformed by compression (Figure 6). The structure at Espanola seems best explained upon the assumption that only the Huronian rocks in that area made up the unit which carried the deforming thrusts. However, about 40 miles north of west from Espanola, in the vicinity of May and McCabe lakes, some of the Huronian formations are preserved in a syncline within Archæan rocks; and 10 miles southeast of Espanola area the Huronian formations have been folded into La Cloche mountains. Unquestionably, Espanola terrane is part of a much larger unit of deformation which has been outlined recently by Collins.[3] Yet, on account of the great thickness of

[1] Except for the case of so weighty an overburden that incipient relief by flexure is not possible, when the weakening due to flexure does not occur, and the strength of the column form approaches that of a short block.

[2] The behaviour of a plate is most like that of a pin-and-square ended column.

[3] Collins, W. H., Geol. Surv., Can., Mus. Bull. 22, 1916, p. 6.

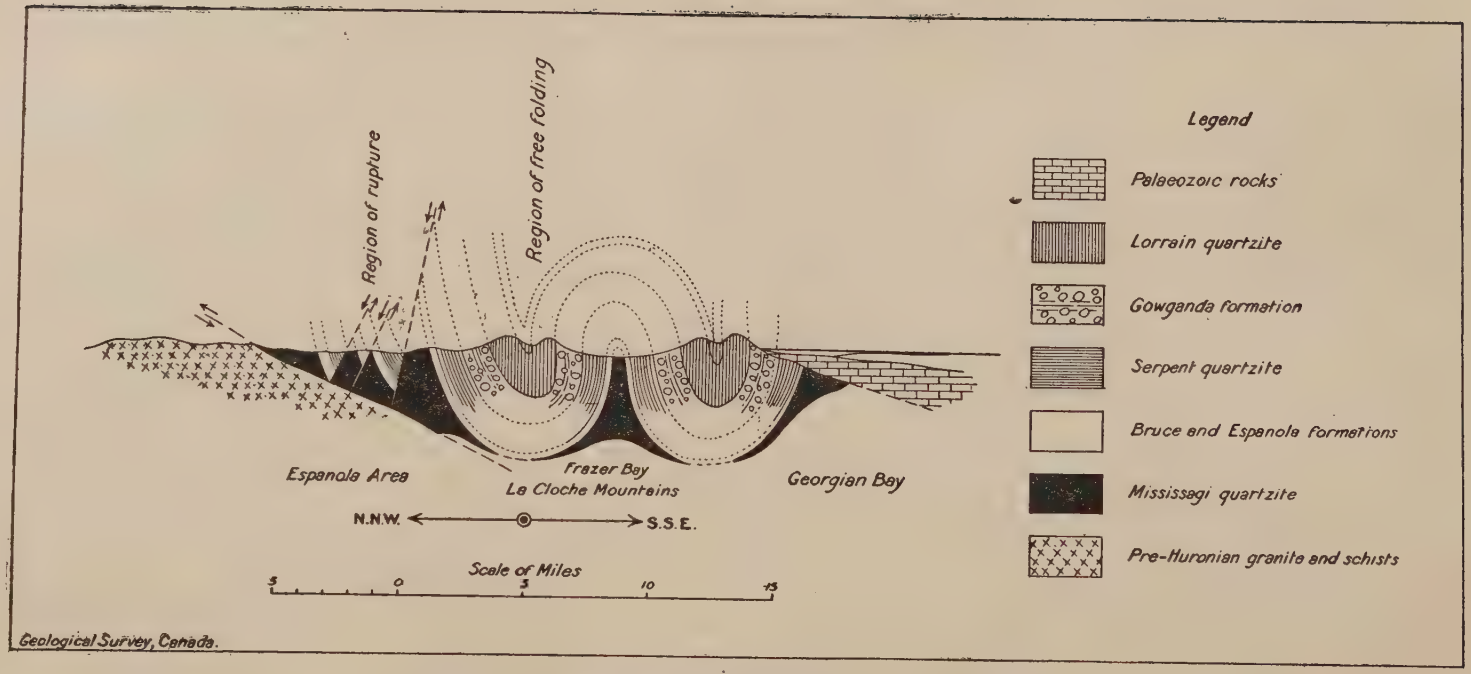


Figure 6. Idealized section of the deformed Huronian terrane.

the Huronian series in La Cloche mountains, and on account of the massive character of the pre-Huronian rocks north of Espanola, the region between La Cloche mountains and the pre-Huronian rocks to the north may have been a structural unit within a greater one. Therefore, there is justification for discussing the deformation of Espanola terrane without further reference to the diastrophism of these other areas.

In the Bruce series there are 700 feet of greywackes and limestones, very incompetent formations, which are much crumpled and folded. There are thick massive quartzite members, thousands of feet thick, above and below the deformable formations. Above the upper Bruce quartzite lies 600 feet of Cobalt conglomerate, which is a competent formation overlain by incompetent slate, which, in turn, is overlain by massive conglomerate and thousands of feet of quartzite. The greywackes between the quartzites, and the slate within the conglomerates, fortified by their rigid neighbours, seem to have had little influence on the whole, which was a rigid compilation.

It is assumed that the Bruce and Cobalt series, like most sedimentary deposits, had lenticular shapes, and that the younger was deposited upon the other in such a way that together they formed a lens-shaped whole. Although they are anomalous in their conglomerate formations, for the most part, they were laid down as coarse arenaceous clastics near the land, progressively growing first thicker, and then thinner and more argillaceous towards the deep parts of the basin of deposition. Thus, there were competent formations near the land on the north side, and incompetent rocks at the other side far to the south (Figure 7).

Upon subjection to compression, bending started somewhere about the middle of the member, probably nearer the south end than the north end, and the pelitic, pliable materials folded into and around the end of the quartzite formations, and made in effect a round end to the member; but this must have been far south of La Cloche mountains. The landward side, in Espanola area, was probably held rigidly by strong abutments, chiefly the pre-Huronian schists fortified by pre-Huronian granite masses. Thus, bending started near the free end in Espanola area, and the whole local member assumed the warped form indicated in Figure 8. Being a competent and rigid compilation, the terrane broke at the step fold.[1]

The stratigraphic throw of the fault may have been as much as 7,000 feet. On the assumptions that the beds were horizontal, and that they ruptured at an angle of 40 degrees to the horizontal, the displacement along the fault plane would amount to about 10,900 feet,

[1] Willis, Bailey, U.S. Geol. Surv., 13th Ann. Rept., 1891-92, p. 228.

Figure 7. Supposed lens shape of Bruce and Cobalt deposits before deformation.

and the horizontal movement to about 8,400 feet. Thus, the fault would cause a surficial shortening of about 1½ miles, which requires that the whole mass on the upthrust side of the fault, to an unknown depth, moved bodily a long way, probably shearing over the old pre-Huronian surface. This carries the assumption that the ancient basement was not involved in the transmission of these thrusts, and the assumption is based on the fact that there is an overthrust fault between the Huronian and the pre-Huronian outcrops.

According to this the strained member was reduced in length by 1½ miles. It is believed that the terrane had the form of a lenticular plate, and the behaviour of a plate is essentially the same as that of a column.[1] According to Euler's formula, the strength of a long column, and, therefore, a long plate also, is proportional to

$$EI\,\frac{\pi^2}{L^2},$$

in which E = coefficient of elasticity of the material involved, I = moment of inertia, and L = length of column. Therefore, the strength of a long column or plate is inversely proportional to the square of its length. By making such a change that L^2 in the formula is altered to $(L-1\frac{1}{2}\text{ miles})^2$, the strength of the member is much increased, especially so if L is not very great. L was probably not over 20 miles; thus, the strength of the member at Espanola area was increased by shortening (other factors being neglected) in the ratio of

$$\frac{1}{20^2} \;:\; \frac{1}{18\cdot 5^2} = 25 : 29,$$

which is an increase of 16 per cent. The first break involved four main pieces of work: (1) rupture across the beds; (2) a parting or a flow, permitting the mass to move horizontally forward, to take up the heave of the fault; (3) overcoming the friction of the mass along both the base and the true fault planes; (4) the movement of that great mass through the distance of displacement. The first of these was probably the least.

The next break occurred in the thickened part of the wedge, and in a shortened member, but the basal zone was weakened so much that it took a smaller force to cause the break in spite of the strengthening factors. It is assumed that the different shortenings of the same terrane provide a means of comparing the accumulated forces. In the second faulting, the throw was less than one-quarter as great as in the first, and, therefore, the force relieved is supposed to have been smaller than the first rupturing stress. The stratigraphic throw of the

[1] Church, I. P., "Mechanics of Engineering," 1909, p. 383. Church applies Rankine's formula to the buckling of a plate, but Rankine's and Euler's formulas are fundamentally the same.

second fault is estimated at 1,500 feet, and the horizontal movement at about 1,800 feet.

The third reverse fault was greatest. Its stratigraphic throw is between 10,000 and 14,000 feet, resulting in a heave of 2 or 3 miles. A very great stress must have accumulated, and the terrane must have been very strong to have withstood the growing forces which finally ruptured it. The second fault had thickened and shortened the member as the first fault had done before, and in a similar manner the third fault added to the strength of the compressed terrane. Figure 8 shows the postulated relations of these three faults; the earliest fault is marked *AA*, the second one *BB*, and the third *CC*, and the supposed sole is marked *AZ*.

It is possible that the outermost fault followed those farther south, which would be similar to the process obtained experimentally by Cadell.[1] There is no datum available to prove which of the three faults is the oldest, although it is clear that the most southerly fault followed the one which it cuts in Foster township; but the structure seems to be explained reasonably under the supposition that the outermost fault was the first to occur.

After the third break, the terrane had a weakened base due to the thrust movements, and all the boundaries of the blocks or slices between the three reverse faults were planes of weakness, so that they were in condition to become tilted and rotated under further compression (Figure 8d). At this stage, there was a free sole (*AZ*) under the greater part of the member. Its strength to resist rupture was still very great, and its most ready relief consisted in the extension of the sole into a great thrust fault. During this fault movement, each formation became more tilted, each of the thrust fault planes was rotated into a higher angle, and the whole mass rode forward along the low-angled shearing plane (Figure 8d, *ZZ*).

The last movement is like that of pushing together an outspread pack of cards, and it involves great intra-formational shearing. Plate VI shows a piece of oak wood which has been compressed at a high angle to the direction of its grain, and there has been slip between every one of the strong planes in the block; bedding planes of a compressed formation behave in the same way as the grain in the wood. This intra-formational shearing forms essentially an imbricate structure,[2] only instead of slice faults transverse to the bedding of the formations, there are many shearing planes parallel to the highly dipping bedding.

---

[1] Cadell, H. W., "General description of the geological structure of the region affected by post-Cambrian movements in the North-West Highlands," Geol. Surv., Great Britain, Mem., 1907, p. 474.

[2] "General description of the geological structure of the region affected by post-Cambrian movements in the North-West Highlands," Horne, J., Geol. Surv., Great Britain., Mem., 1907, pp. 463-64.

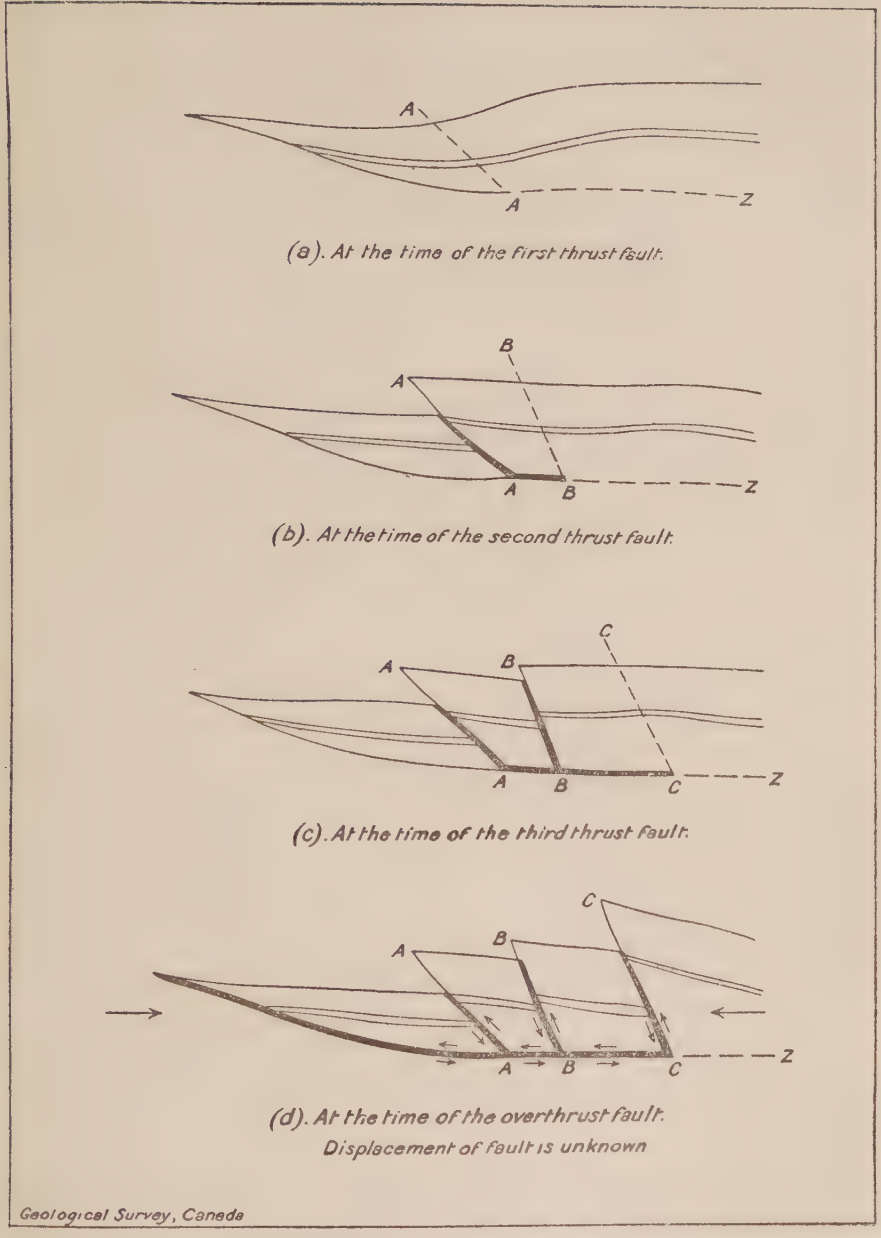


Figure 8. Hypothetical structure of Huronian formations at Espanola.

Some of the quartzites show a marked development of schistose bands at sub-equal spacing, and the ready weathering of these micaceous layers produces the rutted surface mentioned on pages 26 and 27. It is worth suggesting that probably these zones are due not alone to original inequalities in deposition of the quartzites, but largely to the localization of shearing strains within the competent formation; and the mineralogical changes in these micaceous zones are controlled both by impurities localized in the quartzites and by the mechanical, equalized distribution of shear within the relatively homogeneous formation.

Assumptions.

(1) Continuation of the overthrust fault under the whole area is assumed. (2) That it lies everywhere between the pre-Huronian basement and the Huronian members is an extrapolation of the conditions north of Spanish river, described on page 61. (3) The order of succession of some of the faults as assumed, and the foregoing discussion is based in part upon the hypothesis that the overthrust fault followed in time the three large reverse faults. Careful search for pre-Huronian fragments in the fault breccia was made in the hope of finding whether the older rocks were involved in the displacement. Nothing was found to show that they were involved, but that is negative evidence and the case is not proved. The fault displacements are estimated upon the apparent present thickness of the formations, which may not be the same as before deformation, and upon an assumed average angle of rupture which may be erroneous. The computed horizontal shortening along the three main reverse faults amounts to 4 or 5 miles. The displacement of the overthrust fault is not known, although in some places the displacement appears to be 2 miles farther than in other places, nor is there any measurement of the movement along the bedding planes. According to these considerations, the total horizontal movement appears to have been many miles. (5) The original shape of the Huronian series is not known; it is assumed to have been normal, but perhaps it was not. (6) As stated on page 72 the assumption that the outermost thrust fault preceded the other two faults may be wrong, but it seems most reasonable.

So many assumptions would be unpardonable, were data obtainable; in this case the smallness of the area studied, the drift covering, the slight relief of the surface, and the metamorphism of the rocks, combine to conceal the facts. It seems better to advance a tentative hypothesis, dependent upon assumptions as it is, than to leave an interesting problem with no solution attempted.

Facts in Conclusion.

Irrespective of assumptions, some conclusions are justified. The Huronian rocks at Espanola were strained by great compressive forces which shortened the terrane in a north-northwest direction.

The resultant movements have five main effects: (1) The formations are in a steeply tilted position. (2) The rocks have suffered great mineralogical and textural alterations. The quartzites are sheared and sericitized, the greywackes are folded and changed to slaty rock, the conglomerates are sheared and chloritized, and the limestones are squeezed and crumpled into marble. (3) There was great intra-formational shearing along numerous, sub-equally spaced planes parallel to the bedding. (4) The Bruce series is thrust upon the pre-Huronian basement along an overthrust fault plane, at least as regards the outcrops between the Algoma Eastern and the Canadian Pacific railways. (5) There is repetition of parts of all the members of the Bruce series.

PLATE I.

A. Skyline from a hill near Webbwood, looking north. (Page 9).

B. Decadent cliff on the shore of Moon lake near the outlet. The cliff faces southward. (Page 16).

PLATE II.

A. Typical outcrop of Bruce limestone on the northwest shore of Brazil lake. (Page 34).

B. Solution hemispheres in Espanola limestone on the north shore of Griffin lake. (Page 38).

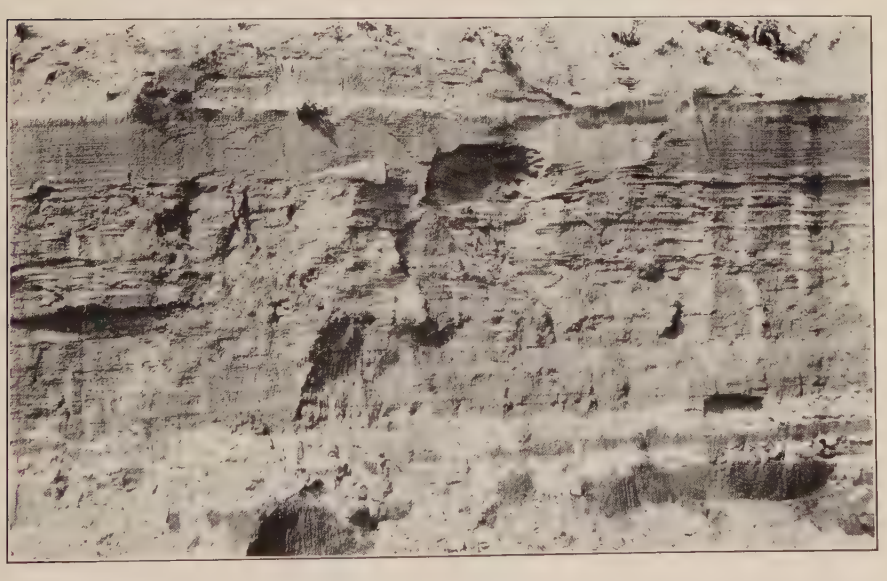
PLATE III.

A. Ripple-marks and mud cracks in Serpent quartzite beside the railway, 5 chains south of Tulloch lake. (Page 38).

B. Pebbly, quartzitic dykes cutting Espanola greywacke on the northeast shore of Apsey lake. (Page 39).

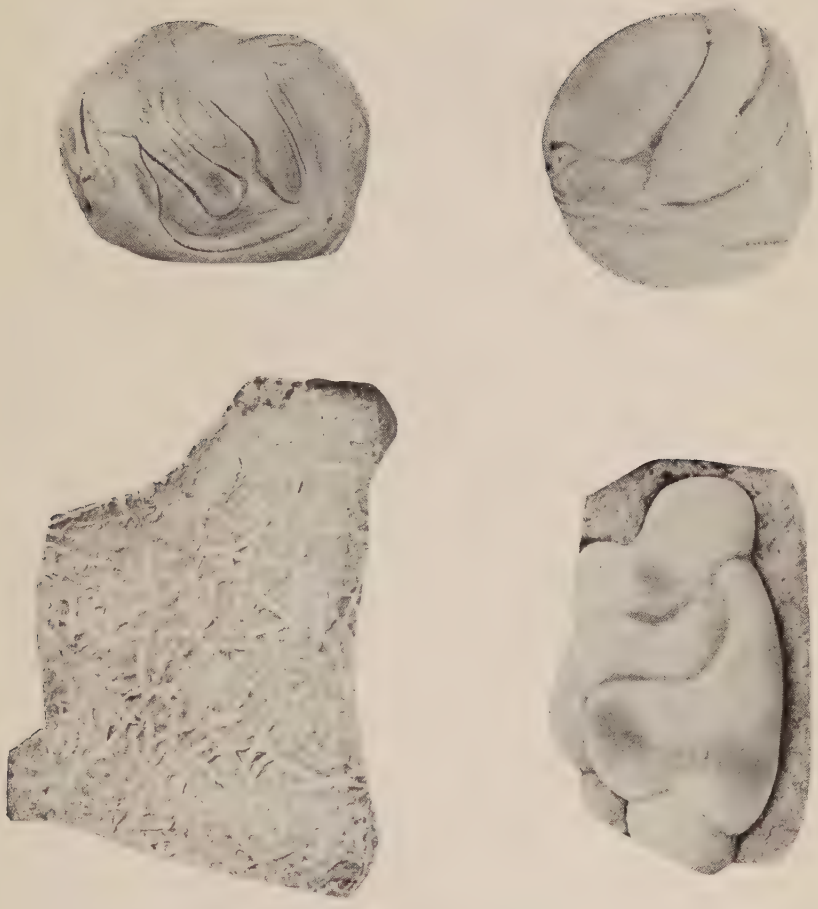
PLATE IV.

A. Serpent quartzite showing the lining due to feldspar and quartz laminations, about half a mile southwest of the dam on Elizabeth lake. (Page 40).



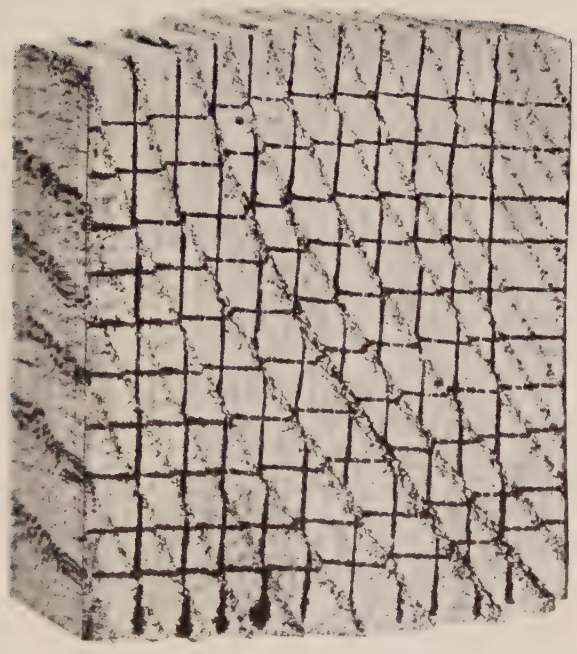
B. Post-glacial, interlaminated clay and sand deposits, showing a granite inclusion 8 inches long, below the dam at Espanola mills. (Page 56).

PLATE V.



Marlekor or imatra stones. Nos. 1 and 2 show the effects of rolling before they were indurated. No. 3 bears peculiar little ridges of unknown origin. No. 4 is an argillaceous mass cemented to a piece of granite. Its shape suggests that of a viscous fluid. Photos by Dr. L. C. Snider. (Page 58).

PLATE VI.



A wooden block compressed in a direction transverse to the grain, showing planes of differential shearing. Specimen and photo by Mr. Walter Long. (Page 72).

INDEX

PAGE

A.

Abrasion 15
Absorption 51
Acknowledgments 1
Agriculture 3
Alaskite 23
Algoma Eastern railway 1
Algoma station 5
Algoman 22
Anderson lake 38, 40
Apsey lake 34, 38, 39, 40, 62
Area 1
Augusta lake 39, 40, 41

B.

Bailey, W. S 54
Baldwin tp 3
Barlow, A. E 14
Basic intrusions 21
Bastin, E. S 53
Bell, R 3
Benoit, Arthur 1
Blind river 24
Bowdoin canyon 17
Bowen, N. L 53
Brazil lake 30, 34
Bridgland tp 13
Bruce conglomerate 28
" limestone 34
" series 5, 24, 25, 59
Brushes, feldspar 53

C.

Cadell, H. W 72
Cambrian 10
Canyons 12
Chamberlin, R. T 1
Chicago university 1
Chrystocrene transportation 17
Clays, stratified 6, 56
Cliffs 12
Cobalt conglomerate 43
" series 5, 42, 59
Cockfield, W. E 1
Coleman, A. P 3, 5, 21, 29, 32
Collins, W. H 1, 3, 5, 7, 48, 53, 56, 67
Communication 1
Concretions 56
Conglomerate dyke 41, 47
Contact between Serpent quartzite and slate conglomerate 44
Cretaceous 10

D.

Devonian 10
Diabase 12, 13, 16, 51
" dykes 5
" Keweenawan 49
" olivine 51
" quartz 50
Drainage 11
Dunes 55
Dyke, conglomerate 41, 47
Dykes, quartzitic 39

PAGE

E.

Elizabeth lake 39, 40, 41
Erdmann, A. 57
Erosion 15
Espanola greywacke 35
" group 5, 33
" limestone 36
" Mills 1, 3, 55
" station 1

F.

Faults 6, 25, 29
" minor 62
" overthrust 61
" thrust 62
Fluvioglacial 6
Foster tp 3, 45
Fracture zones 39

G.

Gabbro porphyrite 51
Galbraith tp 13
Glacial 55
Glacial boulders and conglomerate 33
Glaciation 14
Gowganda formation 5, 43
" slate 47
Granite 22
Gregory, H. E. 48
Greywacke, Serpent 38
Griffin lake 29, 35, 36, 39, 62
Grout, F. F. 54

H.

Hallam tp 3, 20, 21
Haughton tp 13
Heath, H. J. 1
Hematite 27
Huronian 24

I.

Imatra stones 56
Intrusions, basic 21
Ithaca-Chemung 10

J.

Johannsen, A. J. 1
Johnson, W. D. 15

K.

Kewagama lake 57
Keweenawan diabase 49
Kjerulf,— 57
Knight, C. W. 5

L.

La Cloche mountains 3, 43, 67
Lamination of the quartzite 40
Lawson, A. C. 22, 25
Liesegang, R. F. 57
Limestone, Espanola 36
Location 1
Long Lake mine 52
Loon lake 30, 41
Low, A. P. 17
Lumbering 3

PAGE

M.

Mackinnon tp 44
Marlekor 56
Marshall, John R 1
Martin, Lawrence 10
May lake 67
McCabe lake 67
Mechanics of the postulated movements 64
Merritt 1, 4
" station 35, 38, 40, 41
" tp 3, 13, 22
Metamorphism 13
" contact 51
Mica phenocrysts 20
Miller, W. G 5
Mississagi quartzite 25
" series 5
Moon lake 16

O.

Olivine diabase 51
Onondagan epoch 9

P.

Palisades of Tendinenda lake 16
Panache lake 3, 27
Peneplain 10
Permian Squantum tillite 48
Phyllite 20
Physiography 9
Pigeon point, Minnesota 54
Pleistocene 6, 55
Porphyrite, gabbro 51
Post-Glacial 55
Potsdam 10
Pre-Huronian 59
Pre-Huronian sediments 19
Previous work 3
Proterozoic 10
Pulp mills 3

Q.

Quartz diabase 50
Quartzite 12, 13, 16
" Serpent 38
Quaternary 55

R.

Richters, F 57
Ripple-marks 56
Rose tp 13

S.

St. Leonard lake 40, 41
Salisbury, R. D 1, 11
Sand-plain 55
Sands, lake 6, 55
Saugeen beds 56
Sayles, R. W 48
Schist, greywacke 20
" micaceous 20
" quartzitic 21
" staurolite 20
Schuchert, Chas 10
Sediments, Pre-Huronian 19

	Page
Serpent quartzite	5, 38
Shakespeare tp	3, 20, 21
Silurian	10
Slate conglomerate	43
" " Bruce Mines	33
" Gowganda	47
" micaceous	20
Solution holes	37
Spanish river	3, 20, 55, 56
" River Pulp and Paper mills	3
Spheroidal weathering	49
Stratigraphy	19
Stratton lake	27, 34
Stresses, character of	64
Structure	59
Sudbury	21
Syenite	23

T.

Table of formations	6
Talus	15
Temiskamian	5
Tendinenda lake	16
Tertiary	11
Till	6
Tillite, Pre-Cambrian	49
Timiskaming, lake	56
Todd, E. W	1
Topography	4
Transportation	1
Tulloch lake	5, 29, 38
Tyrrell, J. B	17

U.

Unconformities	7

V.

Valley	13
Van Hise, Chas	10
Vermilion river	3, 30

W.

Webbwood	3
" station	20
Weidman, S	10
Whiskey lake	22, 24
Willis, Bailey	65
Wilson, A. W. G	10, 14
Wilson, M. E	10, 48, 57